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CLIMATE CHANGE

SCIENTIFIC ASSESSMENT AND POLICY ANALYSIS

Biomass Assessment:

Assessment of the applicability of biomass for energy and materials

MAIN REPORT

Milieu en Natuur Planbureau
Universiteit Utrecht
WAGENINGEN UR For quality of life
vrije Universiteit amsterdam
ECN Energy research Centre of the Netherlands
uce Utrecht Centrum voor Energie-onderzoek Utrecht Centre for Energy research

This study has been performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change

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Assessment of the applicability of biomass for energy and materials

MAIN REPORT

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Wetenschappelijke Assessment en Beleidsanalyse (WAB)

Het programma Wetenschappelijke Assessment en Beleidsanalyse klimaatverandering in opdracht van het ministerie van VROM heeft tot doel:

- Het bijeenbrengen en evalueren van relevante wetenschappelijke informatie ten behoeve van beleidsontwikkeling en besluitvorming op het terrein van klimaatverandering;
- Het analyseren van voornemens en besluiten in het kader van de internationale klimaatonderhandelingen op hun consequenties.

Het betreft analyse- en assessment werk dat beoogt een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. Deze analyse- en assessment activiteiten hebben een looptijd van enkele maanden tot ca. een jaar, afhankelijk van de complexiteit en de urgentie van de beleidsvraag. Per onderwerp wordt een assessment team samengesteld bestaande uit de beste Nederlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Klanten zijn met name de NMP-departementen, met VROM in een coördinerende rol, maar tevens maatschappelijke groeperingen die een belangrijke rol spelen bij de besluitvorming over en uitvoering van het klimaatbeleid.

De verantwoordelijkheid voor de uitvoering berust bij een consortium bestaande uit MNP, RIVM, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het MNP is hoofdaannemer en draagt daarom de eindverantwoordelijkheid.

Scientific Assessment and Policy Analysis

The programme Scientific Assessment and Policy Analysis is commissioned by the ministry of the environment (VROM) and has the following objectives:

- Collection and evaluation of relevant scientific information for policy development and decision–making in the field of climate change;
- Analysis of resolutions and decisions in the framework of international climate negotiations and their implications.

We are concerned here with analyses and assessments intended for a balanced evaluation of the state of the art for underpinning policy choices. These analyses and assessment activities are carried out in periods of several months to about a year, depending on the complexity and the urgency of the policy issue. Assessment teams organised to handle the various topics consist of the best Dutch experts in their fields. Teams work on incidental and additionally financed activities, as opposed to the regular, structurally financed activities of the climate research consortium. The work should reflect the current state of science on the relevant topic. The main commissioning bodies are the National Environmental Policy Plan departments, with the Ministry of Housing, Spatial Planning and the Environment assuming a coordinating role. Work is also commissioned by organisations in society playing an important role in the decision-making process concerned with and the implementation of the climate policy. A consortium consisting of the Netherlands Environmental Assessment Agency (MNP), RIVM, the Royal Dutch Meteorological Institute, the Climate Change and Biosphere Research Centre (CCB) of the Wageningen University and Research Centre (WUR), the Netherlands Energy Research Foundation (ECN), the Netherlands Research Programme on Climate Change Centre of the Vrije Universiteit in Amsterdam (CCVUA**)**, the International Centre for Integrative Studies of the University of Maastricht (UM/ICIS) and the Copernicus Institute of the Utrecht University (UU) is responsible for the implementation. The Netherlands Environmental Assessment Agency – MNP as main contracting body assumes the final responsibility.

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Abstract

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Executive Summary

This study provides a comprehensive assessment of recent biomass potential studies, focusing on the various factors affecting these potentials, such as food supplies, water use, biodiversity and agro-economics. After an extensive inventory the study integrates the complicated linkages between these various factors, quantifying the consequences of the results of the assessment within the limits of the presently available models. The results are translated into an overview of the uncertainties in biomass resource potentials and knowledge gaps, leading to policy relevant recommendations for sustainable biomass use in the future, including R&D needs.

The assessment of eight major biomass potential studies focused on insight in the linkages between the impacts of (large-scale) use of biomass for energy and materials on: food supplies, water use and biodiversity, taking into account agro-economic and GHG effects and results of demand modelling. It was found that all studies looked only at part of the relevant parameters, so none could provide a complete picture. An important reason is that the relationships between these issues are complex and therefore cannot (yet) be captured in detail by a single study or model. Figure ES.1 below illustrates this complexity by highlighting some key relationships and assumptions.

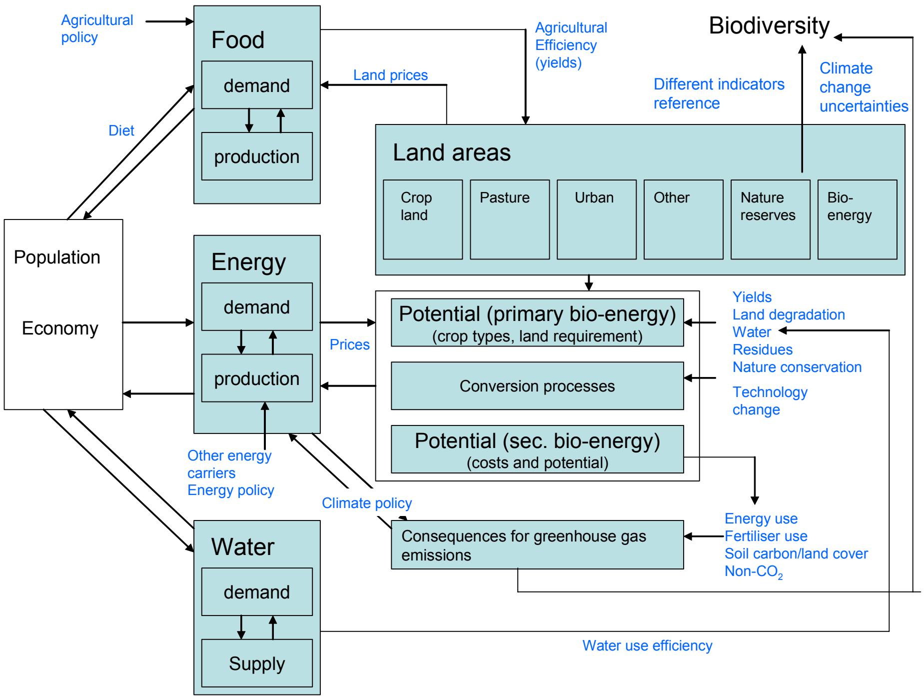

Figure ES.1: Overview of key relationships relevant to assess potential bio-energy supply.

In the integration part of the study insights are provided into the possible impacts of more integrated considerations and the effects of key uncertainties, by performing sensitivity analysis using existing models (MARKAL and TIMER). The integration analysis provided answers to a few key questions, but also showed knowledge gaps and uncertainties. Some examples (see also section 4.4):

Is water a limiting factor for biomass potentials?
In general, water availability can be a limiting factor for the production of biomass and food. A simple and rough analysis in this study has shown that excluding water scarce areas decreases the biomass potentials with 30-50 EJ/yr for woody bio-energy crops, in a scenario with biomass potentials of about 200 EJ/yr in 2050. Water availability, however, has not been analyzed on a sufficient detailed spatial level to estimate regional biomass potentials in water scarce areas.

What is the relation between biodiversity conservation and using bioenergy?
Studies that estimate biomass potentials assume in general that nature conservation areas are excluded from biomass production. As such estimated biomass potentials consider biodiversity conservation on a base level. Assuming that larger parts of land should not be used for biomass production for reasons of biodiversity conservation, potentials would decrease accordingly. In most cases perennial lignocellulosic crops have lower impacts on biodiversity than annual sugar, starch and oilseed crops and are, thus, better suited for combining biodiversity and biomass production.

What is the effect of biomass use on food prices?
Economic analyses indicate clearly that food prices increase with an increased demand for biomass, but the magnitude of this increase is uncertain. However, in the long term, price increases might accelerate agricultural efficiency leading to larger potentials of food and biomass mitigating price increases. For example, OECD and FAO project an increase of coarse grain prices of about 30% in the short term and about 10-20% in the medium term of 2010-2016 compared to 1996 level. But only part of these projected price developments is due to the increase of biofuel production, while other parts are due to low recent harvests and increasing other demands.

Main conclusions of the study
Current understanding of the potential contribution of biomass to the future world energy supply is that the total supplies could range from a minimal 200 up to 1500 EJ/yr theoretical potential per year. The present study gave more insight in the various factors and the biomass resource categories, tuning down this broad range to 200 up to more than 400 EJ/yr (two left columns of fig ES.2 below)

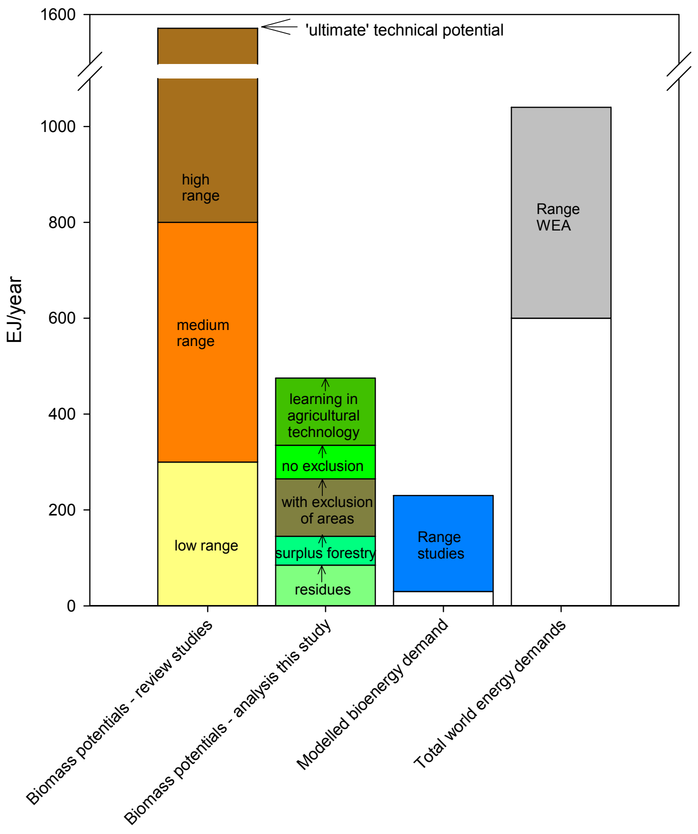

Figure ES.2: Comparison of biomass supply potentials in the review studies and in this study with the modelled demand for biomass and the total world energy demand, all for 2050.

The potential consists of three main categories of biomass (second column in fig ES.2):

1. Residues from forestry and agriculture and organic waste, which in total represent between 40 - 170 EJ/yr, with a mean estimate of around 100 EJ/yr. This part of the potential biomass supplies is relatively certain, although competing applications may push the net availability for energy applications to the lower end of the range. The latter needs to be better understood, e.g. by means of improved models including economics of such applications.
2. Surplus forestry, i.e. apart from forestry residues an additional amount about 60-100 EJ/yr of surplus forest growth are likely to be available.
3. Biomass produced via cropping systems:
    a. A lower estimate for energy crop production *on possible surplus good quality agricultural and pasture lands*, including far reaching corrections for water scarcity, land degradation and new land claims for nature reserves represents an estimated 120 EJ/yr ("*with exclusion of areas*" in fig ES.2)
    b. The potential contribution of *marginal and degraded lands* for energy crop production, could amount up to an additional 70 EJ/yr. This would comprise a large area where water scarcity provides limitations and soil degradation is more severe and excludes current nature protection areas from biomass production ("*no exclusion*" in fig ES.2).
    c. *Learning in agricultural technology* would add some 140 EJ/yr to the above mentioned potentials of energy cropping.

Another result of this assessment is that the demand for bio-energy until 2050 is probably much smaller than the potential biomass supplies, because other energy options are more competitive in terms of specific mitigation costs. This may in particular be true for power generation because alternatives such as wind energy, fossils with Carbon Capture & Storage and nuclear energy, are more attractive. Energy demand models calculating the amount of biomass used if energy demands are supplied cost-efficiently at different carbon tax regimes, estimate that in 2050 about 50-250 EJ/yr of biomass are used. At the same time, scenario analyses predict a global primary energy use of about 600 – 1040 EJ/yr in 2050 (the two right columns of fig ES.2).

This assessment has provided several corrections of available results to date, especially with respect to water availability, soil quality and protected areas. These are significant and led to corrections to earlier estimates of the resource potentials.

This assessment also showed different trade-offs from biomass/bio-energy production on biodiversity. On a local scale, biodiversity may benefit from growing biomass, when intensive agricultural practices are replaced by low-intensity biomass production systems (such as short-rotation forestry, mixed land-use systems). On a global scale however, agricultural lands may only become available when food production regions will shift, for instance through trade liberalization. Thus, the short-term global biodiversity effects are intimately related to global land-use dynamics and especially the different causes of land abandonment. On the long term, biomass production is expected to contribute to reduced greenhouse gas emissions and, therefore, reduced climate change effects on biodiversity. A first order estimate indicates that the balance between global biodiversity losses from increased land-use and reduced climate change effects from biomass production alone is not beneficial for biodiversity within 50 years. However, this conclusion is surrounded by considerable uncertainty, especially on climate change effects but also with respect to net biodiversity values of vegetation patterns and cropping systems. The latter may be strongly influenced by good practices and governance of land use. This element deserves further research.

Policy advice and conditions for sustainable development of biomass resources

Policies in support of sustainable development of biomass resources could cover:

- Development and commercialization of key technologies
- Defining and applying sustainability criteria for biomass and biofuels trade.
- Investments in infrastructure (agriculture, transport and conversion)
- Modernization of agriculture, crucial for many developing countries.
- Nature conservation and biodiversity protection.
- Regeneration of degraded lands (and required preconditions)

This study has confirmed that annual food crops are not suited as a prime feedstock for bio-energy, both in size and in terms of meeting a wide array of sustainability criteria. Perennial cropping systems, however, offer very different perspectives. These cannot only be grown on (surplus) agricultural and pasture lands, but also on more marginal and degraded lands, be it with lower productivity. At this stage there is still limited (commercial) experience with such systems for energy production, especially considering the more marginal and degraded lands and much more R&D work is needed to develop feasible and sustainable systems suited for very different settings around the globe. This is a prime priority for agricultural policy.

This assessment points out that policies targeting development of bioenergy use and biomass production should incorporate a variety of targets and boundaries. Including a strict GHG criterion will lead to different choices for crops and land management compared to a situation where no criterion is formulated. This is also true for sustainable management of water resources, biodiversity, as well as rural development. Clearly, the balance of objectives will be different from setting to setting (compare rural Africa with the EU for example) and trade-offs have to be made. It is argued here that such trade-offs should be explicit, balanced and incorporate clear boundaries that should be respected and used as a starting point for developing biomass production in a given region. Governance and deployment of incentives could then also be designed to achieve just that.

1 Introduction

In a wide variety of scenarios, policy strategies and studies that address the future world energy demand and the reduction of greenhouse gas emissions, biomass is considered to play a major role. Over the past decades, the modern use of biomass has increased rapidly in many parts of the world. In the light of the Kyoto GHG reduction targets, many countries have ambitious targets for further biomass utilisation. Rising oil prices have also increased the level of interest in bioenergy.

Current global energy supplies are dominated by fossil fuels (388 EJ per year). Biomass provides about 45 ± 10 EJ, making it by far the most important renewable energy source used. Much smaller contributions are from hydropower (28 EJ) and nuclear power (26 EJ). On average, in the industrialized countries biomass contributes less than 10% to the total energy supplies, but in developing countries the proportion is as high as 20-30%. In quite a number of countries biomass supplies 50-90% of the total energy demand. A considerable part of this biomass use is, however, non-commercial and relates to cooking and space heating, generally by the poorer part of the population. Part of this use is commercial, i.e., the household fuel wood in industrialized countries and charcoal and firewood in urban and industrial areas in developing countries. An estimated 9 ± 6 EJ are included in this category. [WEA, 2000 and 2004]

Modern bioenergy (commercial energy production from biomass for industry, power generation, or transport fuels) makes a lower, but already significant contribution (some 7 EJ per year in 2000), and this share is growing. Biofuels, mainly ethanol produced from sugar cane and surpluses of corn and cereals, and to a far lesser extent biodiesel from oil-seed crops, represent a modest 1.5 EJ (about 1.5%) of transport fuel use worldwide. Global interest in transport biofuels is growing, particularly in Europe, Brazil, North America and Asia (most notably Japan, China and India) [WEA, 2000/2004; IEA, 2006b]. Global ethanol production has more than doubled since 2000, while production of biodiesel, starting from a much smaller base, has expanded nearly threefold.

Due to rising prices for fossil fuels (especially oil, but also natural gas and to a lesser extent coal) the competitiveness of biomass use has improved considerably over time. In addition, the development of CO_2 markets (emission trading), as well as ongoing learning and subsequent cost reductions for biomass and bioenergy systems, have strengthened the economic drivers for increasing biomass production, use, and trade. Sufficient biomass resources and a well-functioning biomass market that can assure reliable, sustainable, and lasting biomass supplies are crucial preconditions to realise such ambitions. To date, various countries have considerable experience with building biomass markets and linking available resources with market demand. Examples are found in Brazil, Sweden, Finland, Canada, and the Netherlands. Relatively recently, international trade in biomass resources has become part of the portfolio of market dealers and volumes traded worldwide have increased at a very rapid pace with an estimated doubling of volumes in several markets over the past few years [Faaij, et. al., 2005].

Biomass and bioenergy are now a key option in energy policies. Security of supply, an alternative for mineral oil and reduced carbon emissions are key reasons. Targets and expectations for bioenergy in many national policies are ambitious, reaching 20-30% of total energy demand in various countries. Similarly, long-term energy scenarios also contain challenging targets. The expectations for bio-energy are therefore very high.

Because of the ‘globalisation of bio-energy’ and the steeply increased demand for both liquid and solid biofuels, biomass supplies (e.g. pellets from agricultural and forest residues, vegetal oils such as palm oil and rapeseed, bio-ethanol) from other continents are now used in various markets. This triggered a heated debate on the sustainability of those developments, because biomass production is now also associated with increased competition with food production and land, loss of forest cover and the like. Besides such competition, also the net reduction in GHG emissions is questioned in case land-use for biomass is associated with clearing (virgin) forest, conversion of peat land, as well as high fossil energy inputs for machinery, fertilisers and other agrochemicals.

If biomass is to contribute to levels representing up to one third of the global future energy supply during this century, this implies that land-use implications are very significant. Views on such potential developments differ from ‘utterly destructive’ to feasible and possible to develop biomass potentials in synergy with rural development and sustainable management of natural resources. The latter, more positive views, are supported because rationalisation of agriculture has beneficial effects and biomass may also be produced on marginal and degraded lands not suited for production of food, with possible ecological benefits.

Proper standardisation and certification procedures to ensure sustainable biomass production and use are currently being developed. Currently, this is a priority for various governments, market players, and international bodies. In particular competition between production of food, preservation of forests and nature and use of land for biomass production should be avoided. It is often stated that this may be possible by using lignocellulosic biomass resources that can come from residues and wastes, which are grown on non-arable (e.g. degraded) lands and in particular by increased productivity in agricultural and livestock production. Demonstration of such combined development where sustainable biomass production is developed in conjunction with more efficient agricultural management is a challenge and it is questioned to what extent strict sustainability demands will influence biomass resource potentials over time.

The potential for energy crops depends largely on land availability considering that worldwide a growing demand for food has to be met, combined with environmental protection, sustainable management of soils and water reserves, and a variety of other sustainability requirements. Given that a major part of the future biomass resource availability for energy and materials depends on these complex and related factors, it is not possible to present the future biomass potential in one simple figure.

Focussing on the more recent estimates of biomass resource potentials, energy farming on current agricultural (arable and pasture) land could, with projected technological progress, contribute 100 - 300 EJ annually, without jeopardising the world’s future food supply. A significant part of this potential (around 200 EJ in 2050) for biomass production may be developed at low production costs in the range of 2 €/GJ assuming this land is used for perennial crops [Hoogwijk, 2005b; WEA, 2000]. Another 100 EJ could be produced with lower productivity and higher costs, from biomass on marginal and degraded lands. Regenerating such lands requires more upfront investment, but competition with other land-uses is less of an issue and other benefits (such as soil restoration, improved water retention functions) may be obtained, which could partly compensate biomass production costs. Combined and using the more average potential estimates, organic wastes and residues could possibly supply another 40-170 EJ, with uncertain contributions from forest residues and potentially a significant role for organic waste, especially when bio-materials are used on a larger scale.

Key to the introduction of biomass production in the suggested orders of magnitude is the rationalization of agriculture, especially in developing countries. There is room for considerably higher land-use efficiencies that can more than compensate for the growing demand for food [Smeets, et. al., 2007].

Available studies already indicate that the results are sensitive to assumptions about crop yields and the amount of land that could be made available for the production of biomass for energy uses, including biofuels. Critical issues include:

- *Competition for water resources:* Although the estimates mentioned above generally exclude irrigation for biomass production, it may be necessary in some countries where water is already scarce.
- *Use of fertilisers and pest control techniques:* Improved farm management and higher productivity depend on the availability of fertilisers and pest control. The environmental effects of heavy use of fertiliser and pesticides could be grave.
- *Land-use:* More intensive farming to produce energy crops on a large-scale may result in losses of biodiversity. Perennial crops are expected to be less harmful, or even able to achieve positive effects compared to conventional crops such as cereals and seeds. More

intensive cattle-raising would also be necessary to free up grassland currently used for grazing.

- *Competition with food and feed production:* Increased biomass production for biofuels out of balance with required productivity increases in agriculture could drive up land and food prices.

Although available studies give a reasonable insight in the importance of various parameters, the integration between different arenas is still relatively limited. This causes confusion in public as well as scientific debate, with conflicting views on the possibilities for sustainable use of biomass as a result. This study aims to tackle this problem by providing a more comprehensive assessment of the current knowledge with respect to biomass resource potentials.

Main objectives of this assessment study:

1. To provide clear insight in the linkages between the impacts of (large-scale) use of biomass for energy and material on food supplies, water use, nature and biodiversity, and in macro-economic terms.
2. Provide insight in regional and site-specific elements in the above mentioned issues.
3. To translate the results of the assessment into an overview of the more and less certain issues with respect to biomass resource potentials and to policy relevant recommendations on how to develop and use biomass resources in a sustainable way, including research and development needs.

Set up of the work:

- Part 1 comprises an extensive assessment of recent literature on the key areas distinguished: biomass potentials and land use, food production, water, biodiversity and macro-economic analyses. Furthermore, GHG balances of biomass use for energy are distinguished as a separate topic. Distinction is made between various biomass resource-technology combinations and different settings for biomass production.
- Part 2 is an integration component, which describes the linkages between the different key areas and quantifies the consequences of the results of the assessment to the extent that available models and tools allow doing so. A limitation of this study is that no new models will be developed.
- Part 3 translates the results of the assessment and the integration activities into an extensive assessment of the uncertainties of future biomass resource potentials and which factors are of major and which of lesser importance. Based on this, policy recommendations further steps to reduce uncertainties and fill gaps in knowledge are identified.

This Main Report covers Part 2 and 3, while Part 1 is reported in the Supporting Document.

Main Report structure:

Chapter 2 presents a summary of the results of the assessment work in Part 1. The detailed results of the assessment per key area can be found in the Supporting Document.

Chapter 3 describes the tools with which the integration efforts are undertaken, defines the scenarios that were used for the analyses and gives the results of the interlinkages that could be quantified and translated into consequences for biomass resource potentials. The scope and limitations of current tools and approaches are discussed, with detailed information given in appendices.

Chapter 4 provides the synthesis of the findings of chapter 2 (assessment) and chapter 3 (integration) and discusses the overall findings, determining factors for biomass resource potentials as well as the uncertainties.

Chapter 5 provides an overall judgement of the current knowledge on biomass resource potentials and outlines (partly per key area) how uncertainties and gaps in knowledge could be addressed and dealt with by policies on shorter and longer term.

2 Results of the assessment activities

In this chapter a summary is given of the review of recent relevant studies in the field of biomass potentials, biodiversity, water, food demand and energy demand. These are the relevant areas for estimating the potentials of biomass for energy and material purposes

The review describes the most important aspects and parameters that should be taken into account in an 'ideal study'. Common to all areas is that global trends on population growth and economic development are an important basis to estimate future development. Within the review, the key parameters on the current situation and on the future developments that resulted from the various studies are presented. Finally, conclusions are drawn regarding important relations of the separate areas with biomass potentials and possible knowledge gaps. The full description of the review including a detailed comparison of recent studies is included in the Supporting Document of this study.

2.1 Biomass potential studies

2.1.1 Introduction

Earlier analyses of biomass potential studies had shown large ranges of outcomes that were based on differences in methodologies and assumption on crop yields and available land and in the case of economical potentials also on differences in the estimated production costs. (Berndes, 2003)

An 'ideal' study to evaluate biomass potentials should take into account global and regional trends and *specific local conditions* such as soil types, water availability, possibility of irrigation and land use planning taking biodiversity and soil quality into account. Moving to the large-scale use of biomass for energy and materials is expected to change land-use patterns and energy systems significantly. Such changes would influence supply and demand of (agricultural) land as well as those of food, materials, wood products and energy carriers in a dynamic way. The *economic relationships between the demand and the supply of biomass*, especially taking into account changes of land and food prices on a regional to local level, should therefore be considered.

2.1.2 Review of studies

In this assessment, we focus on the relation between estimated biomass potentials and the availability and demand of water, the production and demand of food, influence on biodiversity and economic mechanisms. For this purpose, we analyzed 8 recent studies. None of these studies covers the whole range of issues, but they all have strong points at certain issues.

The scope of the studies, in terms of biomass resources included, varies as well as the scenario assumptions. As a consequence, global biomass potentials vary widely (Figure 1). The high biomass potential for 2050 determined by Smeets et al. (2007) shows potentials under intensive, very high technologically developed agriculture. On the contrary, the low biomass potential for 2050 calculated by Wolf et al. (2003) is caused by high population growth, high food demands and extensive agricultural production systems. The study of (Hoogwijk et al. 2005) refers to production of energy crops on abandoned, marginal and rest land assuming global and regional trends as described in the IPCC SRES scenarios, under increasing agricultural efficiency over time Finally, the study of Rokityanski et al. (in press) determines economic potentials of afforestation and reforestation, excluding other types of biomass and assuming extensive forestry management. As a result, the economic potentials for 2100 are rather low.

Reducing greenhouse gas (GHG) emissions is a major driver for using biomass for energy and materials. Many studies deal with GHG balances of biomass production and uses even though

GHG emission reduction is not explicitly analyzed in the biomass potential studies reviewed. Most biomass chains turn out to reduce net GHG emission, but the results vary depending on the type of crop, the type of energy or material use, the land use changes involved and the fossil energy reference system. In general, second generation biofuels are more favorable than first generation biofuels as they tend to require lower energy inputs for biomass production and have a higher efficiency of biomass conversion.

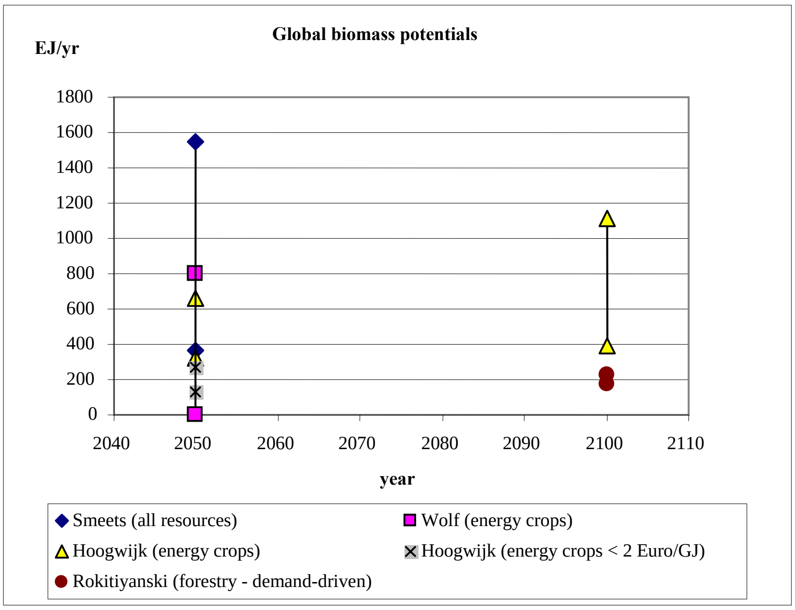

Figure 2.1.1: Ranges of estimated global biomass potentials

2.1.3 Conclusions review biomass potentials

The recent biomass potential studies give more detailed and well-founded insights into future biomass potentials, but none of the studies does include all critical aspects. Important issues that remain unresolved are:

- The competition for water with other economic sectors, as well as the possibilities of irrigation, has not been included in the biomass potential studies.
- The competition for water with other economic sectors, as well as the possibilities of irrigation, have not been included in the biomass potential studies.
- Human diets and alternative protein chains have been poorly included in the potential estimates, while the impacts of different animal production systems needs to be studied in more detail and applied to more biomass potential studies
- The demand for wood products and other bio-materials has been simplified in most studies and has not been modelled based on economic scenario analysis.
- The impact of large-scale biomass production on the prices (and subsequently) demands of land and food has not been sufficiently studied.
- The impact of specific biodiversity objectives on biomass potentials has not been investigated in detail.

2.2 Biodiversity

2.2.1 Introduction

The number of worldwide species has shown a fast decrease in the last few centuries, most importantly through land-use change. This has raised considerable policy interest, and has led to two global UN Conventions that contain targets on preventing further biodiversity decline. The Climate Convention (UNFCCC) has a long term goal to prevent damage to biodiversity from climate change effects, next to mitigating climate change itself. The CBD Convention wants to reduce the rate of further loss by 2010, and is focused on a broad range of causes for the decline, among which land-use change.

Biodiversity is a complex phenomenon, and can therefore not simply be defined and measured. It includes the variability of all living organisms and all ecosystems. All possible indicators are imperfect to capture the full complexity, but they are useful if they can be monitored and explained, related to human impact and modeled to show future developments and the effects of policy choices. Several complementary indicators are used within the CBD-framework, an important global policy arena where agreement on the indicators used is essential. However, different indicators might give different messages because of different definitions and implicit valuation of biodiversity, for instance when indicators based on “naturalness” or contrary on “agro-biodiversity” are used.

Several types of impact assessment can be distinguished:
1. Assessing local and present impacts of biofuel cultivation.
2. Assessing integral, global impacts of biofuels in a LCA-approach, comparing the effects of biofuels and fossil fuels over the whole production chain on greenhouse gas emissions, land-use and biodiversity effects.
3. Regional and global scenario studies, showing the integral and future effects of biofuels, in combination with other global developments in population growth, food demand, diets and agricultural productivity.

An ideal study should take all relevant aspects and scales into account, to show not only the local effects, but possible shifts and trade-offs as well.

2.2.2 Review of studies

Local impact studies
For this type of studies, locally specific aspects like irrigation, fertilizer and pesticide use, former land-use and landscape structure are important. In case (1st generation) energy crops are just an element in agricultural rotation systems local effects are negligible. On the other hand, agro-biodiversity is at risk when extensively used low input farmlands are converted to biomass crops. In Europe, protecting this type of biodiversity is a policy objective in its own. Positive effects for local biodiversity are also possible, for instance when replacing intensively managed agricultural systems by extensively managed (2nd generation) perennial crops; or when replacing mono-cultures by extensively used mixed systems (agro-forestry, mixed cropping, organic farming).

LCA-studies
In LCA-studies the global and integral impact of biofuels on biodiversity depends strongly on the following aspects:

- The integral reduction of greenhouse gas emissions (with fossil fuels as a reference, but also comparing different applications of the same biomass) per hectare of land used, depending on technology, soil characteristics and climate. Liquid biofuels based on perennial and woody crops (2nd generation) as well as sugarcane ethanol and palm oil generally provide better results than (1st generation) European crops. However, changes in land-use might lead to an increase of CO_2-emissions in case carbon is released from the soil.
- The loss of biodiversity related to specific land-use changes. In general the cultivation of natural areas leads to significant loss. In case of the cultivation of abandoned land the effect in time depends on the restoration time of biodiversity values. The values of cultivated land depend on management practices and crop type.
- The (reduced) long-term effect of climate change on biodiversity, which is hard to quantify because of high uncertainties on the long term.

For most (especially 1st generation) liquid biofuels the overall impact on biodiversity is very likely to be negative. For none of the biofuels a positive impact can be guaranteed.

General scenario studies
There are hardly any global scenario studies that take all relevant aspects of the biofuel debate into account. For the CBD's 2nd Global Biodiversity Outlook (GBO2), a global analysis was performed by MNP. A broad measure portfolio including large scale use of bio-energy was part of an ambitious climate change option. In this study, the indicator MSA ("mean abundance of original species") was applied to express global biodiversity loss. This aggregated indicator can be interpreted as a measure of naturalness or ecosystem intactness. It can be disaggregated to regions or biomes and can be modeled for future projections. It is not intended to highlight individual species under threat, agro-biodiversity or the specific value of protected areas.
The analysis indicated that increased land-use of mainly abandoned land and marginal grounds for growing bio-energy crops leads to biodiversity losses on the short term (as compared to a baseline scenario). In the baseline, the assumption is that abandoned agricultural lands will restore to more-or-less natural situation. By 2050, the increased loss is not yet counteracted by gains through avoided climate change effects. In determining whether short-term losses can be balanced by long-term gains, uncertainty should be taken into account. Long-term effects are based on modelling exercises that are surrounded with considerable conceptual and data uncertainty. The local and specific characteristics and biodiversity values of the economically defined "marginal grounds" are also not well known. Further, there is uncertainty on the assumption on fast and complete biodiversity restoration on fallow land.

2.2.3 Conclusions review biodiversity

Published studies on the biodiversity effects of growing bio-energy crops are very diverse and show opposite results. These differences are the result of using different time horizons (short and/or long term), different scales of observation (local, regional or global), and the different biodiversity definitions used (for instance naturalness or agro-biodiversity). More often then not, the used biodiversity indicators are not explicitly defined.

The integral global impacts of biofuels on biodiversity depend mainly on the long-term positive effect of reduced future climate change and the short-term negative effect of land-use change for large scale energy crop cultivation instead of nature. In determining whether short-term losses can be balanced by long-term gains, uncertainties should be taken into account. The short-term effects have a high degree of confidence as the effects of local land-use change are based on monitored effects, while long-term effects are based on modelling exercises that are surrounded with considerable conceptual and data uncertainty. This finding shows that it is not easy to combine both the short-term CBD biodiversity goals and the long biodiversity goals of the Climate Convention.

In all cases a negative impact results from additional land use for large-scale biomass production. European first generation agricultural crops do worse at the local level than tropical and second generation perennial and woody crops. Further, not all biodiversity indicators might show the same results, especially when agro-biodiversity and naturalness are confronted. Finally, especially the important uncertainties about the positive effects of reduced climate change on biodiversity make it hard to draw conclusions about the future impact of biofuels all together.

2.3 Water

2.3.1 Introduction

Quantification of the spatial and temporal distribution of river runoff and assessing the influence of humans form the backbone for decisions on optimal use of water resources. A common classification of water resources is that in blue and green water flows. Blue water flows refer to water in rivers, lakes and groundwater. Green refers to water in the rooted zone of the soil originating directly from rainfall that is available to plants. Globally around 80% of agricultural evapotranspiration (crop water depletion) originates from green water, while the remaining 20%

is provided through irrigation (blue water withdrawals) (Molden et al., 2007). 20-50% of blue water, depending on the local situation, is required for environmental requirements and services. In addition, water is required for industrial and domestic use.

At the regional and local scale, *irrigation efficiency* is a major determinant of water use. It is often defined as the net crop water requirement for evapotranspiration as part of the water withdrawn from a water source. A typical value would be 40%. Most of the other 60% is captured and recycled somewhere else in the system. As reuse loops of water are very common in river basins, improving irrigation efficiency becomes a very complex issue. *Water productivity* (WP) indicates the efficiency of water use, including blue and green water. Crop WP is an indicator of crop yield per unit of water consumed (evapotranspiration). This implies CWP depends on the main product. If the plant parts used for energy and food are not the same, CWP of a crop differs for both purposes. Water use by crops can be estimated based on weather data and crop growth modelling or by a crop specific *Water Use Efficiency (WUE)* that varies among crops and crop types and also with weather and agricultural management, such as input use and other practices. WUE can refer to evapotranspiration, transpiration, total crop yield, economic product, etc. Hence, caution is required when using data from literature.

The ideal study does not exist as several very divergent aspects have to be considered with respect to water. Water availability and water use can be assessed at plant – crop – farm – local – river basin – continental – global scale. Each scale has its own crucial parameters for reliable calculations and estimates. Water use for bioenergy production should be compared with actual water (and nutrient) use and existing or expected bottle necks for water availability have to be identified. As priority is often given to the other uses (food, domestic and industrial water use), all uncertainties and inaccuracies are accumulating in the final assessment of the scope for energy crops.

2.3.2 Review of studies

Expected future water use by industry and domestic sectors differs between different sources, due to different assumptions on technological development (more efficient systems), economy and life-style. Some studies expect it to be more or less constant (Alcamo, 2003) and others expect it to increase by 60-220% (Shlikomanov, 2000). However, the largest part of this use (80%) flows back to rivers, lakes or groundwater. For agricultural water withdrawal, estimates vary considerably depending on the scenarios on population growth, human diet and input levels used; however, in all scenarios water use is increasing. Energy crops are not considered explicitly in these studies. Total water requirements and availability, including the environmental water requirements (EWR) have been expressed in a water stress indicator by Smakthin et al. (2004); Figure 2.3.1. These estimates are in line with other sources (Shlikomanov, 2000; Molden et.al, 2007)

All studies give solutions or directives for improving water use efficiency at certain scales. It is generally acknowledged that quite some improvements can be made. Measures to alleviate water stress are various, e.g. more recycling of industrial and domestic water, change diets towards less water consuming foods and less meat, improve agricultural water productivity by water harvesting and supplemental irrigation and better maintenance of irrigation systems.

At the field scale, high water use efficiency (WUE) of crops can only be achieved if other factors (nutrient availability, incidence of pests and diseases, appropriate and timely management) are not limiting crop production. Hence, in different regions of the world large variations in actual WUE are found. The overall conclusion is that the strong interaction between water, nutrients and management has to be taken into account when estimating opportunities for energy crops.

Most studies agree that climate change will increase rainfall amounts in high latitude areas and will increase rainfall variability and extreme weather events. For the sub-tropical regions rainfall will decrease, increasing water scarcity. However, predicted rainfall changes are uncertain, especially with respect to more detailed spatial patterns.

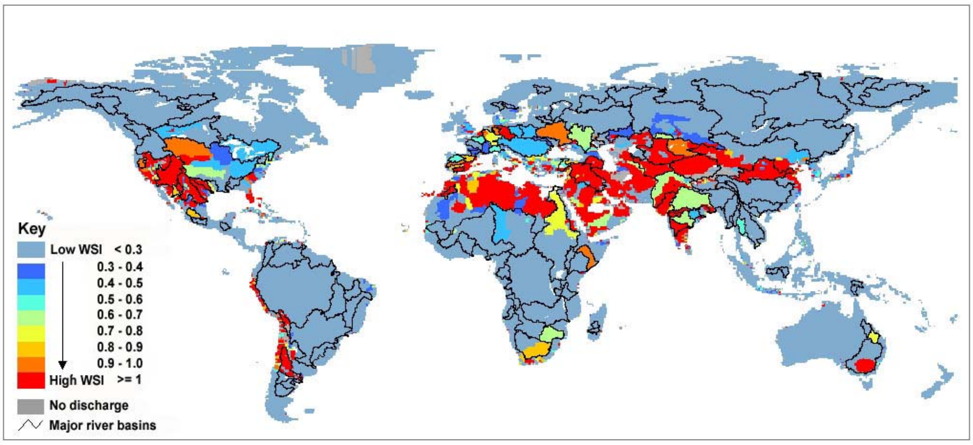

Figure 2.3.1: Water stress indicators (Smakthin et al., 2004)

2.3.3 Conclusions review water demands and availability

Comparing the different analyses shows that problems are analysed at a higher scale than the solutions formulated. The large variability in regional climate and hydrology asks for a more detailed and local analysis of the biophysical possibilities for crop production. The studies analysed show that in some regions water is abundant, providing ample opportunities for energy crops, while in other regions water scarcity seems not provide any opportunity for energy crops.

To determine water availability for energy crop production it is best to execute the following steps:
- estimate renewable water resources on the scale of a ‘river basin’ area
- determine how much water is being used in food crop production and future projections
- verify the available land area for additional crop production
- assess the regional and crop(type) specific WUE of the energy crops to be cultivated
- decide whether water availability or land area is a limiting factor for bio-energy production.

This procedure favours a multi-scale approach taking into account the influence of local measures on the larger regional scale and vice versa. It does not require just straightforward aggregation but a more detailed analysis of relations to arrive at an optimal water distribution. The local situation should be analysed to assess the scope for energy production. However, to date, studies at this resolution have not been executed, and global figures give a misleading picture. A rough estimate of available blue water for energy crops, based on global water flows, is 1,300 – 5,000 km^3, depending on the share required for EWR (50-20%). However, where this is water is available and if it can really be used cannot be determined based on available studies. Future change in rainfall patterns will regionally have a large impact, especially in regions that are already water scarce.

2.4 Food

2.4.1 Introduction

Technologically speaking, producing enough food for even 10 billion people seems feasible (Evans, 1998). In contrast, doing so without compromising sustainability – both by pollution and by resource depletion – will be a formidable challenge (Tilman et al., 2002). Currently, *food production* appropriates about 75% of the available freshwater and 35% of the global land area. While the world population doubled during the second half of the 20th century, in consequence of increasing incomes, its appetite for meat quadrupled, requiring 40-50% of the world grain harvest to be fed to livestock (Evans, 1998). Within the food domain, meat production has a disproportionate environmental impact (Aiking et al., 2006a) and, therefore, environmental impacts of food production are strongly coupled to actual diets.

The key metric with regard to *food demand* is elusive. For example, in the Netherlands the food consumption is about 20% lower than the food production (Quist, 2000). This difference can only be approximated, since the quality of FAO food supply data is poor. Furthermore, food prices are hard to predict.

The ideal study estimating food demand takes at least into consideration 1) world population, 2) economic aspects (including income and food prices), 3) production systems and 4) diet characterisation, 5) in sufficient geographic and temporal detail.

2.4.2 Review of studies

Food demand

The principal food demand projections are by the FAO. (Bruinsma, 2002). These projections address world population growth, diet changes (increased use of animal products), yield increases (including those due to use of GMOs) and economic aspects. Freshwater resources are taken into account, but biofuel production is not addressed. Projections are at a general, aggregate level and quite optimistic with regard to yield increases and the effects of climate change. In general, FAO seems to implicitly and explicitly favour further intensification of agriculture, without paying much attention to the potential of organic production.

The real drawbacks of FAO data are that it regards supply (production + imports - exports) per country, per commodity. That is not a very firm basis and, furthermore, everything after primary production, such as food processing, transport, refrigeration etc. is lacking, and so is innovation in the latter part of the chain.

Other recent studies estimating food demand by OECD and IFPRI were reviewed, but they were considered to have little added value, because without exception they relied on FAO data. The International Food Policy Research Institute (IFPRI) generates annual projections, based on FAOSTAT data, to analyse the effects of policies on global food security, primarily, using their IMPACT model (Von Braun et al., 2005), while the OECD studies from 2005 on were in fact performed in close cooperation with the FAO.

Food production

Primary production systems underlying FAO projections are described in sufficient detail. The majority of farming systems are small-scale operations, particularly in developing countries. Although an inventory of such production systems has been made available by the FAO and the World Bank (Dixon et al., 2001), detailed projections of their development and future contributions to world food production are lacking altogether. The direction and rate of innovation of primary production is taken into account in the FAO projections, but evidently hard to model. Furthermore, availability of food is interrelated to other products, such as feed, fuel and materials derived from crops and livestock in a very complex way.

In striving for sustainable food production and consumption, the protein chain is an excellent starting point (Grigg, 1995; Millstone and Lang, 2003; Smil, 2002b), as on average, 6 kg of plant protein is required to yield 1 kg of meat protein (Pimentel and Pimentel, 2003; Smil, 2000). In theory, a promising solution may be offered by partial replacement of meat proteins with plant protein products (so-called Novel Protein Foods, NPFs) in the human diet. We estimate, conservatively, that - without putting a healthy nutrition in jeopardy - Dutch meat supply could easily be cut by *one third*, i.e. from 140-166 to 100%. Even then, our average protein consumption would be 20% over the RDI (recommended daily intake) and one third of our protein consumption would still be derived from meat. Life cycle assessment showed that a partial transition from animal to plant protein (abolishing feed production but keeping extensive livestock, i.e. feeding on grass and agricultural waste) might result in a 3-4 fold lower requirement of agricultural land and freshwater to start with. Moreover, world wide there is potential for a 30-40 fold reduction in water use (Aiking et al., 2006a). Several economic arguments (Seidl, 2000; White, 2000) indicate, however, that actual practice may be not as straightforward as theory suggests, due to status and cultural trends.

2.4.3 Conclusions review of food demand and production

The principal food demand projections are those by the FAO, which are based on supply (production + imports - exports) per country, per commodity. They are the best available, but the descriptive data is crude and so are the projections based on them. The largest knowledge gap in the available models and data is probably in consumer preferences. Studies of diet change show that in addition to availability and price, status aspects and cultural trends play an important role.

2.5 Energy demand

2.5.1 Introduction

In order to put the assessment of biomass potentials and their interrelations with other land-claiming functions into perspective, an assessment was also made of future energy demand development and the foreseen role of biomass therein. (Note that almost all of these demand-side models also need to make assumptions on availability and cost of biomass, in order to compare competitiveness of biomass and other supply options. As such, it is not possible to make a clear-cut distinction between biomass supply and biomass demand assessments.)

The ideal study has at least the following characteristics:

- It includes all energy-related sectors and applications of feedstock and all options for supplying energy-related services, (i.e. conventional and advanced fossil options and all kinds of renewable options).
- It fills in projected energy demand per sector by economic rules, i.e. by choosing least-cost options at given (external) constraints.
- Costs of the different options are assessed with dynamic and interrelated cost-supply curves that take into account technological learning

2.5.2 Review of studies

For this part, we reviewed six global studies, two for the EU and one for the Netherlands. As expected, mostly the more climate-ambitious or CO_2-stressed scenarios show a higher biomass demand than their corresponding reference or baseline scenarios (In GET, for example, the biomass share in 2100 is only limited by the model-imposed upper limit of biomass use of 200 EJ/yr.) An overview of the demand for biomass as produced by the different global studies is summarized in Figure 2.5.1.

Also in terms of biomass allocation, (i.e. for transport, power or other applications) the models show a very broad range. The dominant area of application strongly depends on the development of alternative climate-neutral options, particularly the hydrogen fuel cell car for the transportation sector. Assumptions on this technology strongly influence whether biomass is applied in transport or in power/heat. Furthermore, the way climate policies are implemented also affects biomass allocation.

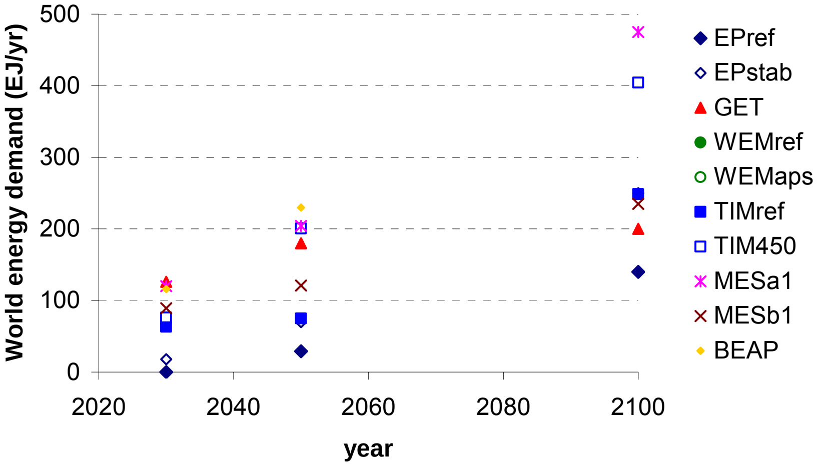

Figure 2.5.1: Biomass demand for energy (EJ/yr) in the different global energy scenarios.

2.5.3 Conclusions review energy demand models

Projections of global demand for biomass by 2100 indicate that we should think of amounts in terms of hundreds of EJ, with a minimum of 150 EJ (in a conservative reference scenario without any climate policy) and a maximum above 400 EJ (in a biomass-intensive scenario with active climate policy).

Relatively weak points in the set of studies are:
- Application of biomass as a feedstock material is hardly elaborated in the models. The only global model that does take it into account predicts a limited, but not insignificant amount of biomass to be allocated to this.
- The majority of all studies work with relatively constant costs for biomass, while it can be expected that this feedstock will show increasing cost with increasing demand.
- Technological learning is included in several studies, but its level of detail is relatively unclear while there will be significant differences between conventional and innovative options in cost reductions due to this type of learning.

2.6 Agricultural economics

2.6.1 Introduction

Economics occupies a special position in the study, because it integrates costs and values. Ideally, it shows “what the society wants”. An ideal economic study on food and bioenergy production takes into account the effects on prices, production, markets of all other crops. It compares the net-return of all possible crops which a farmer can grow. The competition with other markets (food, feed) – determining the output prices of competing markets and crops - is decisive for the economic feasibility of biofuels. The ideal study is able to deal with the interaction between the agro markets worldwide. This is essential due to the fact that (a) bio-energy can be produced using by-products and (b) the production of bio-energy often leads to by-products. Moreover, the ideal study is able to deal with the competing claims of food, feed and fuel on production factors in order to estimate a real economic feasible production of biomass for fuel.

2.6.2 Review of studies

Agro-economic models that use the agro-economic principles described above are just starting with the implementation of the biofuel-options including an analysis of the impacts of the European biofuel directive. Therefore, no overall- overview of consequences and no overview of economic feasible production can be given yet. Furthermore, the economic studies which have been done yet, focus on the first generation biofuels. The second generation biofuels and the use of by products is the second step in the economic models and not implemented yet. Recent results of the Scenar2020 and the EU-RURALIS project that have been carried out in the Netherlands are presented in Section 3.5.

From the other studies found in the literature (i.e. based on the POLYSYS model from the University of Tennessee, the AGLINK model of the OECD, the Ethanol model from Iowa State University) it is clear that the discussions about the fuel sources need to take into consideration impacts on the world agricultural markets.

The driving forces behind agro-production are: demography, global change, political administrative regime, macro-economics, agro-technology and changes in value in society, consumer concerns and behaviour. In studies conducted by the FAPRI, OECD and EU the link with the most relevant data sources (FAO, OECD and EUROSTAT) have been made. It should be noted that those driving forces are influenced by many dynamic developments worldwide. This requires scenario-analyses as is used in most economic studies.

2.6.3 Conclusions review economic models

The agro-economic studies that have been carried out often deal with agricultural land and do not take into account forestry land. They also do not deal with second generation biofuels.

The studies carried out illustrate the necessity of including competition and interactions between agricultural markets. The production of biofuels affects prices of feed and food. Those effects have to be taken into account in order to present a realistic picture of available biomass for biofuel. These effects are also relevant to assess the social sustainability of bio-energy, especially the effects on regional incomes and food security.

The key-parameters for the driving forces behind agro-production vary and are *dynamic*. Therefore, ideally one must work out several scenarios. The worldwide databases of FAO, OECD, and EU etc. are most suitable as a base for the scenarios.

2.7 Overview inventory results

Earlier analyses of biomass potential studies had shown large ranges of outcomes that were based on differences in methodologies and assumptions on crop yields and available land and, in the case of economical potentials, also on differences in the estimated production costs. Recent biomass potential studies give more detailed and well-founded insights into future biomass potentials with regard to:

- the relationship between future scenarios (e.g. SRES) on population growth and economic development and the potentials for bioenergy considering food, energy and material demands
- global cost-supply curves for biomass based on integrated assessment
- a detailed differentiation of land suitability for biomass production of specific crops on a spatially explicit level
- economic biomass potentials based on agro-economic considerations
- different rates of learning and intensification within agricultural management

It can be concluded that the amount of biomass that could be supplied according to recent potentials studies (Figure 2.1.1) are mostly higher than the amounts that might be used according to energy demand models (Figure 2.5.1). Moreover, most biomass chains turn out to reduce net GHG emission, but the results can vary depending on the type of agricultural crop, the type of energy or material use, the land use changes involved and the fossil energy reference system. In general, second generation biofuels are more favourable than first generation biofuels.

Existing knowledge on the impact of agricultural activities is sufficient to show the impact of the land required for bio-energy. However, trade-offs between increased environmental impacts of further agricultural intensification and further land conversion require an integrated indicator for biodiversity. Key issues for an evaluation of the impact of biomass production on biodiversity are

- What is the potential for biodiversity recovery (both natural and aided) for different abandoned land cover types?
- What is the biodiversity value of the different energy crops (short to medium term)
- What is the biodiversity impact of the different management types (extensive vs intensive)
- What is the most likely effect of future climate change on global biodiversity?

With regard to water, it can be concluded that in some regions water is abundant, providing ample opportunities for energy crops, while in other regions water is scarce, leaving no leeway at all. All studies give solutions or directives for improving water use efficiency at certain scales. It is generally acknowledged that quite some improvements can be made. These improvements have to be analysed with a multi-scale approach and are closely linked to possibilities for other improvements in agricultural production systems.

Food production and demand strongly depend on future development with regard to agricultural technology, novel protein chains as well as population growth, economic developments and dietary changes. While technologically speaking, producing enough food for even 10 billion people seems feasible, doing so without compromising sustainability –will be a formidable challenge. Out of the biomass potentials studies, the study by Hoogwijk et al. (2005) came out ahead of the rest from a food demand perspective. The assumptions on food demand that have been made within the SRES scenarios cover a broad range of possible future development that is in line with current FAO projections, which are the best available.

Currently, agro-economic modelling studies as EU-RURALIS start to deal with dynamic supply curves of biomass for energy and materials taking the competition with food production and other sectors into account. The result of this agro-economic modelling exercises show large variations in terms of price dynamics and still need to be interpreted in relation to future biofuel production.

3 Integration of knowledge from assessment areas

3.1 Introduction

In Chapter 2, existing literature on bio-energy potentials and consequences of bio-energy use for issues such as biodiversity, food prices and water use were assessed. This assessment not only provided information on these issues, but also showed key uncertainties. Many of these uncertainties originate from the fact that existing studies have only partly dealt with the linkages between bio-energy use and other issues. For instance, none of the studies on potential for bio-energy considered potential impacts on water use.

An important reason for the conclusion that studies mostly look only at a part of the relevant issues is that the relationships between these issues are complex and therefore cannot be captured in detail by a single study or model. In this context, Figure 3.1.1 highlights some of the key relationships and assumptions that could determine an overall assessment of bio-energy (in blue).

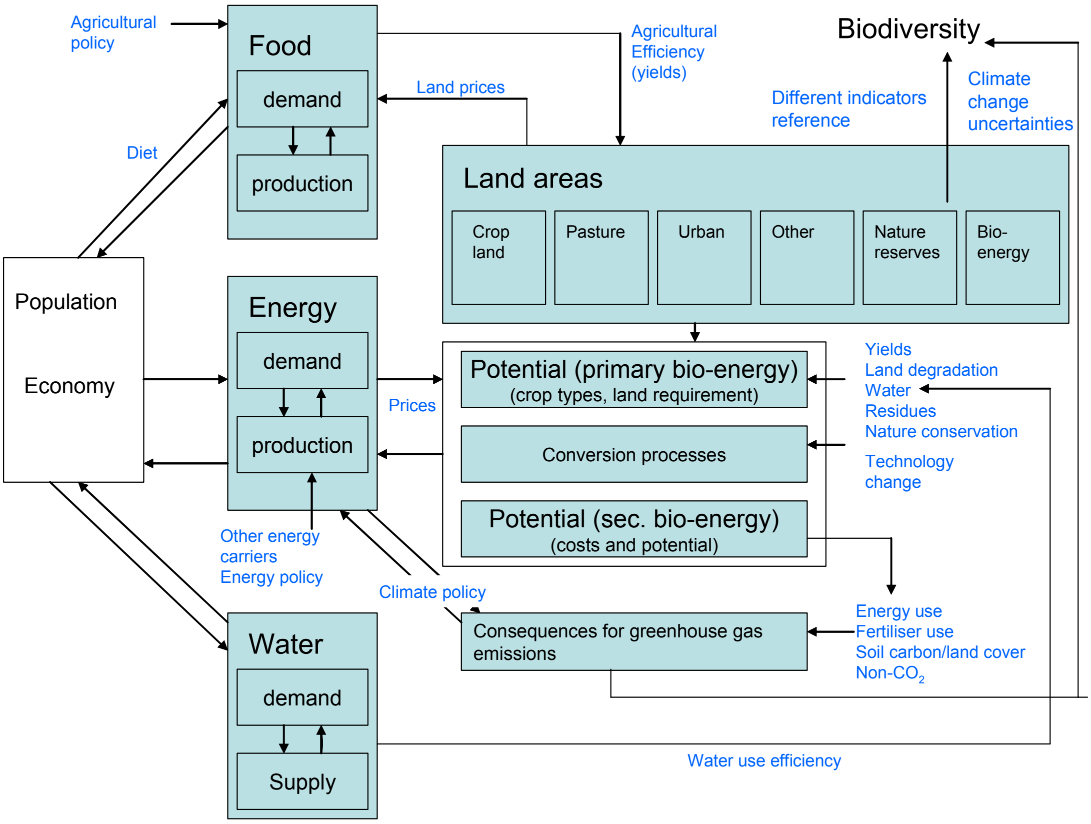

Figure 3.1.1: Overview of key relationships and assumptions relevant to assess potential bio-energy supply.

In this chapter, we aim to provide some insights into the impacts of more integrated considerations by performing some sensitivity analysis using existing models. The aim of these analyses is not to provide quantitative answers – but instead assess the possible impacts of some key uncertainties (selected on the basis that they could be analyzed within the scope of this assessment.

The analysis concentrates on five main issues:

1. The role of bio-energy use in energy models; in particular to identify which factors can limit penetration of bio-energy (potential for bio-energy; long-term cost-supply curve; energy use in specific sectors);

2. The sensitivity of bio-energy potential estimates to issues such as uncertain development of agriculture technologies, land use, water scarcity, land degradation and nature reserves;
3. Key uncertainties in assessing biodiversity losses as a result of land conversion for bio-energy;
4. The economic link between food, feed and fuel;
5. Key results and uncertainties in impacts on greenhouse gas balances.

3.2 Limiting factors to bio-energy use in energy models

In this study two essential questions have been put forward regarding biomass supply potentials and their role in the entire energy economy:

1. To what extent is the role of biomass being limited by its supply potential, and to what extent is the (marginal) cost of biomass-based options the limiting factor for further market penetration? And if the latter is a dominant factor, in which cost range is this marginal biomass cost, and which options are the major competitors for biomass, and what is the influence of carbon taxation on this competition?
2. What is the influence of cost reductions over time, due to technological learning in biomass production and conversion, and in competing technologies such as fossil options with CCS (CO2 capture and storage), fuel cell technology and other renewable options?

These questions were addressed by some additional runs with Timer at MNP, and an analysis of several existing runs with MARKAL at ECN. Timer and MARKAL are both models of the entire energy economy, for the World and the EU15, respectively. Both models use a cost-supply curve for the assessment of biomass feedstock supply and costs. Furthermore, some preliminary results from the REFUEL project are used as an illustration, since these extensively deal with learning effects.

The purpose of this analysis is to provide some more insights in key mechanisms related to the two questions put forward. It is not intended to yield any quantitative results in terms of e.g. bioenergy shares. Details on the models, the scenarios and their key assumptions can be found in Annex A.1 and A.2.

3.2.1 Biomass supply or biomass cost as the limiting factor for biomass penetration?

In order to address this question, several scenarios were analyzed in which potentials and/or costs of biomass were varied. In these scenarios, biomass seems to be mostly limited by its marginal cost, not by its (technical) supply potential. This is especially clear in two Markal runs (see TDT, A1.2.1 and A1.2.3) in one of which the potential of (low-cost) forestry biomass for the energy sector is reduced compared to the other. In both scenarios, the more expensive part of the biomass supply potential remains unused,. Apparently, at high marginal cost for biomass, there are other climate-neutral energy supply options available with a lower marginal cost.

The effect of competition with other climate-neutral options is also illustrated by some scenario runs with variation of CO2 taxation. For example, in Timer and Markal runs in which we increase a CO2 tax and thereby the share of biomass in the primary energy mix, biomass does not reach its maximum supply potential. In the Timer analysis of overall system response to an increase in CO2 taxation (Annex 1 section 1.1 and 1.2), biomass use in 2050 increases at low CO2 taxation levels, but stabilizes at a level of circa 130 EJ at taxation levels above \$100 / tonne carbon (see Figures 3.2.1 and 3.2.2). This is because other climate-neutral options displace additional use of biomass under these circumstances. Biomass supply potential is not the limiting factor here, since this reaches up to 400 EJ in 2030 already; see Annex1. Apparently, the more expensive part of biomass feedstock does not enter the market due to other options such as coal with CCS or other renewable options being more cost-effective, even with a CO_2 tax.

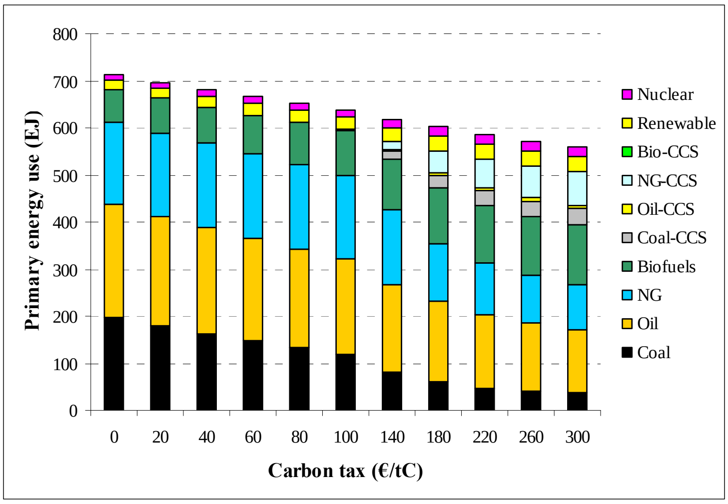

Figure 3.2.1: Overall world energy mix in 2050 at increasing CO2 taxation in a representative Timer scenario.

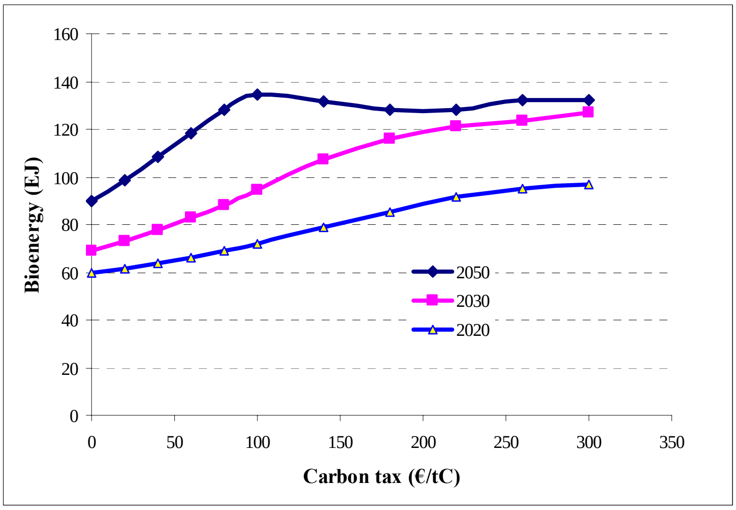

Figure 3.2.2: The supply of biomass in 2020, 2030 and 2050 as a function of carbon taxation in a representative Timer scenario.

Especially in the *power generation sector*, biomass-based options compete with several other technologies, of which several are also climate-neutral. From an indicative analysis with the Timer technology database (Annex 1 section 1.3), the costs of biomass feedstock (at farm gate) were calculated as a function of the CO_2 taxation level. It appears that biomass feedstock for this sector should have costs in the order below 3 US$/GJ by the year 2020 to be fully competitive at carbon prices below 100 US$ per tonne CO_2, and below 4 US$/GJ at carbon prices beyond this point. In 2050, the situation is somewhat changed due to the cost decline of one of the competitors, coal-CCS. As a result, bio-energy costs now need to be below 2-3 US$/t$CO_2$ over the whole range to remain competitive. This is consistent with the marginal cost of the electricity mix (i.e. the price of the marginal kWh of power to which a bio-based option must be competitive) as given by the 2050 Markal CM scenario with a CO_2 taxation of € 100 /tonne CO_2 (see Annex 1 section 2.2), which is ca 6 €/kWh.

In the *transportation sector*, the common competitor of biomass is fossil oil, with natural gas and the hydrogen fuel cell as (innovative) options. Biomass competitiveness therefore also depends on oil prices and the price of CO_2. At oil prices of 40 $/bbl, a Timer analysis (Annex 1 section 1.3) indicates that primary biomass costs (at farm's gate) in the order of 4-5$/GJ are competitive at a carbon price of 150 $/ton carbon and higher.

3.2.2 What is the effect of cost reductions over time due to technological learning?

When analyzing future markets in which innovative technologies will compete with existing ones, a dominant factor is the expected rate of future cost reduction for the new options. Currently being more expensive, these options have a better potential for cost reductions since the technology has not yet matured. In the market for transport fuels, for example, innovative '2nd generation' biofuel options could realise maximum cost reductions of around 40% in the coming decades (Lensink et al., 2007). With conventional biofuels and fossils using more mature technologies, such reductions can lead to new options becoming fully competitive after an introduction period in which they are not competitive.

The fundamentals of technological learning are still not fully understood, but an empirical rule of thumb is that learning rates are higher when more new capacity of a specific technology is installed compared to the existing capacity, and also when exchange of experiences among projects is better. Therefore, assumptions on learning rates are often associated assumptions on the world's economy becoming more globalised or regionalised.

Technological learning will improve opportunities for bio-based options significantly, but the same applies to other innovative (climate-neutral) technologies, such as CO2 capture and storage and the hydrogen fuel cell. Therefore, it is relatively difficult to assess what impact overall higher of lower learning rates will have. Furthermore, estimation of learning rates, as well as production volumes and market sizes in which technologies learn are still subject to debate in the scientific arena. In an indicative Markal run with overall faster learning rates for selected conversion technologies in EU15 (Annex A1.2.2), the role of bio-based options remains relatively unchanged. In the power generation sector it is mainly solar power that profits from improved learning, mainly at the expense of coal-based power. This because solar technology has a significant learning potential and conversion technology is the dominant cost factor in the cost build-up (see Figure 3.2.3). In the transportation sector, improved learning leads to a strong introduction of the hydrogen fuel cell, at the expense of natural gas (see Figure 3.2.4 In this sector the hydrogen fuel cell vehicle has a significant learning potential because the technology is still immature, and the fuel cell costs form a major part of the cost build-up per driven km. Introduction of the hydrogen fuel cell vehicle could induce an increased demand for biomass, since this hydrogen can be produced out of biomass. This production route will compete with fossil-based routes (coal, natural gas), including combinations with CCS, and possibly with production on the basis of renewable electricity.

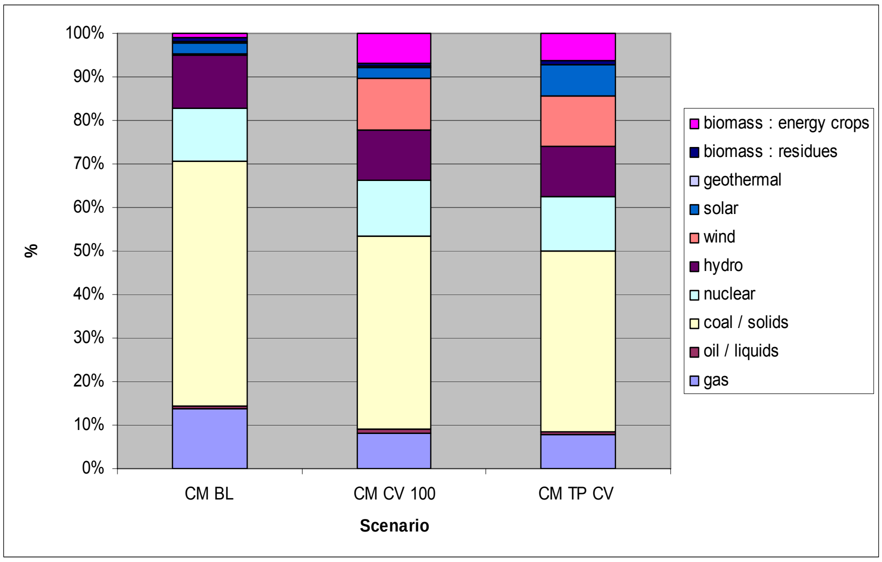

Figure 3.2.3: Shares of different technologies in net electricity generation in the EU15 in 2050 in a Markal baseline scenario (CM BL), a scenario with a CO2 taxation of € 100 /tonne (CM CV 100) and a scenario with the same taxation and improved technological learning (CM TP CV).

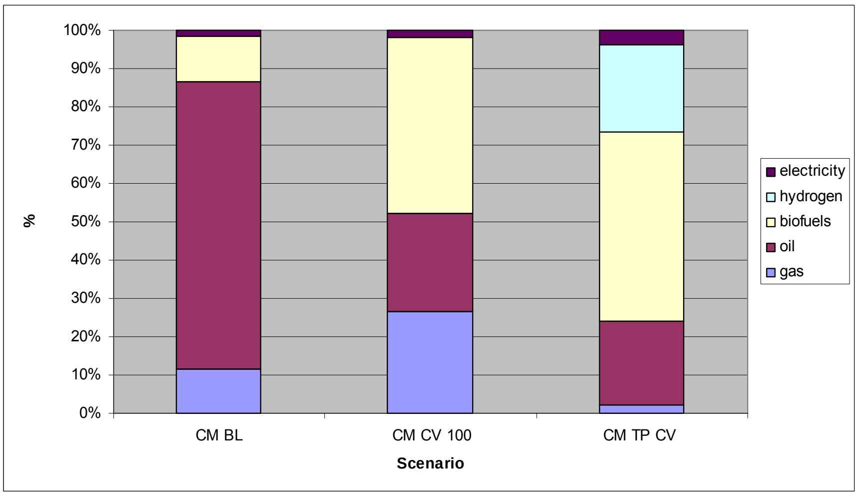

Figure 3.2.4: Shares of different technologies in transportation in the EU15 in 2050 in a Markal baseline scenario (CM BL), a scenario with a CO2 taxation of € 100 /tonne (CM CV 100) and a scenario with the same taxation and improved technological learning (CM TP CV).

3.3 Impacts of some key uncertainties on bio-energy potentials

Estimating bio-energy potentials in IMAGE

In the inventory part of this project (see summary in Section 2.1), we have looked into various estimates for potentials for bio-energy – one of them by Hoogwijk (2004). Compared to others the estimates of Hoogwijk are relatively elaborate – but do not consider issues such as water scarcity or greenhouse gas impacts. In that context, we apply the methodology of Hoogwijk but include some sensitivity analysis to estimate the potential impacts of alternative assumptions.

Hoogwijk's method is indicated in Figure 3.3.1. First, suitable areas for bio-energy are identified on the basis of land use scenarios that do not include bio-energy. In the calculations all areas required for food production are excluded. On the remaining areas a 1) land-specific exclusion factor (between 0 and 100%), 2) the rain-fed potential energy crop productivity (depending on crop, soil and climate) and 3) the assumed state of agricultural management (% of potential production) determine the potential. In the calculation presented here, the exclusion factor for forests and nature reserves is 100%, and 50% for natural grassland ecosystems (e.g. steppe, savannah, grasslands). The total potential is equal to the sum of all areas.

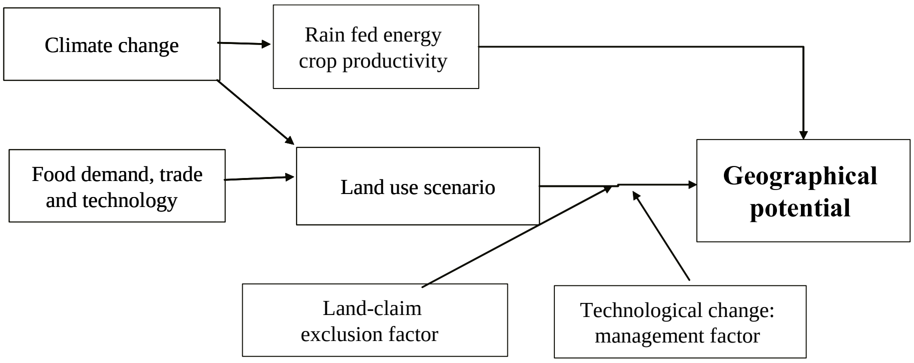

Figure 3.3.1: Methodology of assessing bio-energy potentials

The potential for bio-energy determined thus concentrates on 2 areas:

- abandoned agriculture land (in the short term mainly in developed regions; but later on also in some developing regions)
- natural grass ecosystems (an exclusion factor of 50% is used here, leading to an expansion of total arable area; but outside forest)

Finally, also areas with a very low potential yield (part of tundra and desert ecosystems) are excluded.

Below, we apply the Hoogwijk method and look into the following uncertainties:

- Impact of different scenarios
- The role of different crops and land areas
- Water scarcity
- Land degradation
- Nature reserves

Impact of different scenarios

The analysis of Hoogwijk concentrated on the geographic and economic potential of woody biofuels- using the IMAGE implementation of the IPCC SRES scenarios as a basis. Given new insights into possible future changes, here instead use **the reference scenario of the Netherlands Sustainability Outlook (DV-2)**, which is based on the OECD-scenario. This scenario should be regarded as a 'medium-development' type of scenario (in terms of population and economic change, but also agricultural productivity change). As shown earlier by Hoogwijk and Smeets, scenario-related assumptions, such as for population growth, food demand, agricultural trade and technology change, are very important for the potential for bio-energy. In Figure 3.3.2, the DV-2 scenario is compared to the potential under the SRES scenarios (using only the different land use maps of the updated SRES scenarios; keeping all other factors the same as under the DV-2 scenario). While the primary potential in 2050 of woody bio-energy is around 200 EJ under the DV-2 scenario it ranges from 120 to over 325 EJ under the SRES scenarios (with low potential in A2 as a result of a high population growth, low yields and little trade; and high potentials in A1 and B1 as a result of low population growth and rapid yield change).

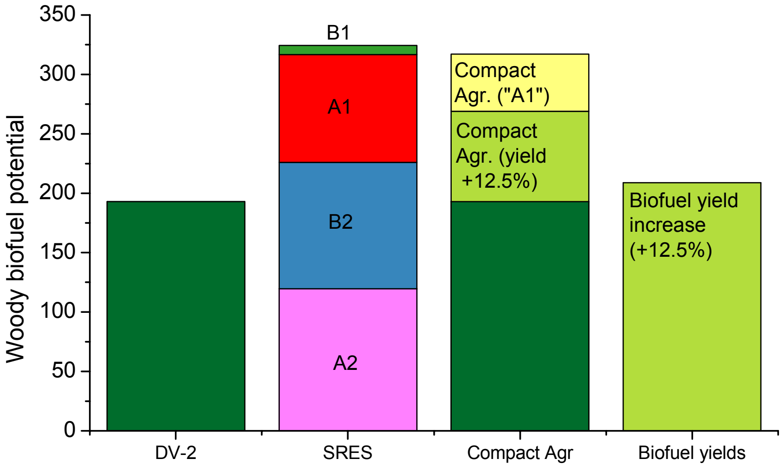

Figure 3.3.2: Potential for primary woody bio-energy (excluding residues?) and using different scenario assumptions

An important factor is the assumed changes in yields. This is also shown in Figure 3.3.2 by showing the two different scenarios that look into a more compact agriculture compared to the DV-2 scenario (and thus higher yields). In the first scenario of a more compact agriculture, agricultural yields are improved for all crops and regions by 12.5% compared to the base case. The value of an additional increase of 12.5% is equal to half the suggested improvement potential compared to baseline in the International Assessment of Agriculture Science and Technology Development [ref]. The second scenario of more compact agriculture applies the same convergence in agriculture yields world-wide as in the A1 scenario, i.e. bringing 2050 technology levels in developing countries close to current Western European levels – while keeping the baseline improvement for developed countries. Both cases lead to a considerable increase in potential compared to the DV-2 scenario: 40% for the first case and about 65% for the second. In other words, assumed yield changes for agriculture in general critical determine the potential for bio-energy – and assuming a more compact agriculture could possibly lead to about 300 EJ/yr of primary woody bio-energy in 2050.

Obviously, also the yield increases for biofuel crops are uncertain. Improving yields for all bio-energy crops also by 12.5% – without improving the yields of other crops above the baseline - leads to an increase of total potential compared to the DV-2 scenario by 12.5%. Thus, the largest gain of agricultural efficiency increases for biomass potentials comes from a possible increase of yields of food crops, while an increase of energy crop yields has a comparable small effect.

Different crops and land areas

In addition to woody bio-energy, also other crops are already applied as feedstock for bio-energy. Woody bio-energy can be applied as feedstock into electricity and heat power plants and as feedstock for second generation biofuels. Other, more conventional agriculture crops, such as sugar, maize, oil-crops and cereals, can also be converted into ethanol or bio-diesel (1^{st} generation). Finally, for second generation biofuels also agricultural residues can be used.

Here, we were only able to estimate the potential (primary) for woody, sugar and maize, shown in Figure 3.3.3 on both abandoned agriculture land and natural grassland. The potential on abandoned agriculture land increases over time – with more abandoned land becoming available. The potential on natural grassland is a function of yields and the area of natural grassland and is more constant. Worldwide, the potential for woody and sugar bio-energy is considerable – while that of maize is only small. The reason is that maize is only an attractive crop for bio-fuel production in the USA and parts of Europe and Asia – where most areas are already used for food production. Sugar has very high yields in developing regions. It should be noted however, that the potential of maize might be underestimated because of model assumptions in IMAGE. The type of fuel chosen does obviously depend strongly on relative prices of crops, animal feed and food. In most cases, woody biofuel seem to become the most dominant feedstock worldwide of the three crops evaluated here.

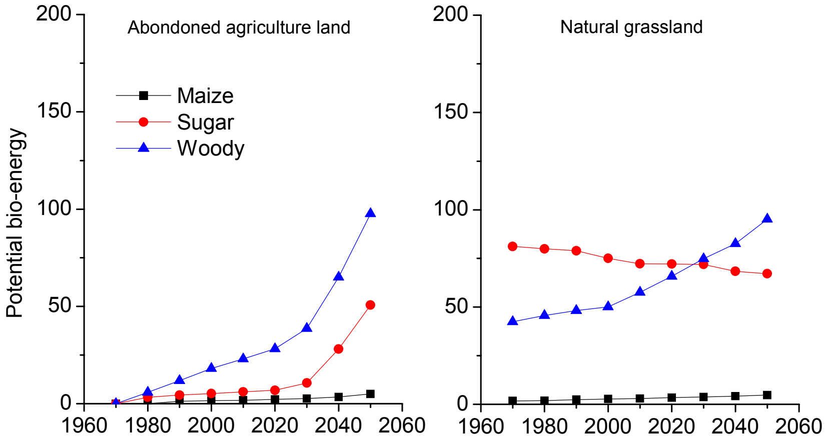

Figure 3.3.3: Potential for primary bio-energy on different crops and land-types in the DV-2 scenario

Water scarcity

All calculations on bio-energy potential have been carried out assuming rain-fed production conditions. On the one hand, this can be regarded as an underestimation given the fact that irrigation is likely to increase yields. At the same time, however, it should be noted that also other sectors than agriculture may be dependent on the same water resources. As an indicator of water scarcity, in analysis of the ratio between water demand and availability is used. Values of this index of 0.2 and higher is defined as modest water scarcity, while values above 0.4 are defined as severe water scarcity. (Smakthin et al., 2004) To fully analyze the potential impacts of bio-energy on water scarcity one should calculate the water demand of potential bio-energy areas (using the water demand factors discussed in the integration analysis (see Summary Section 2.6) and evaluate the impact of increased water demand at grid or watershed level. Some of such analysis has been performed earlier, showing that while impacts are not dramatic on a global scale, on a more local scale water scarcity may clearly limit bio-energy potential.

To assess the possible impact, here a more limited analysis is performed by simply overlaying the bio-energy map with the water scarcity maps of the WaterGap model that assesses water stress (Alcamo et al., 2003)[1]. This overlay suggests that about 15% of the total potential for bio-energy is in severe water scarce areas (and might therefore be excluded), and another additional 5% in modest water scarcity areas (Figure 3.3.5).

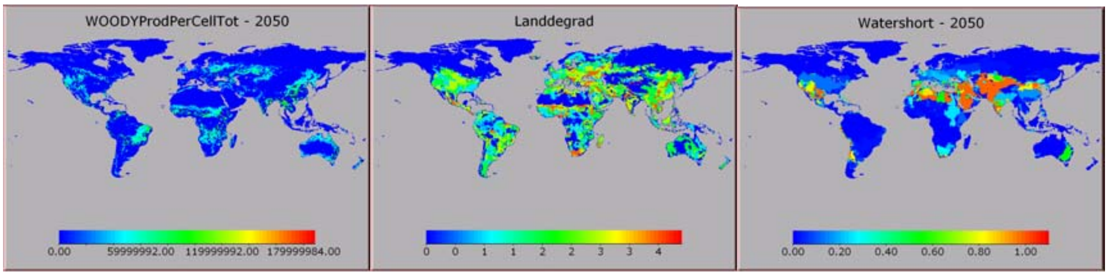

Figure 3.3.4: Maps of woody potential bio-energy production, land degradation, water shortage and nature reserves as used in the analysis

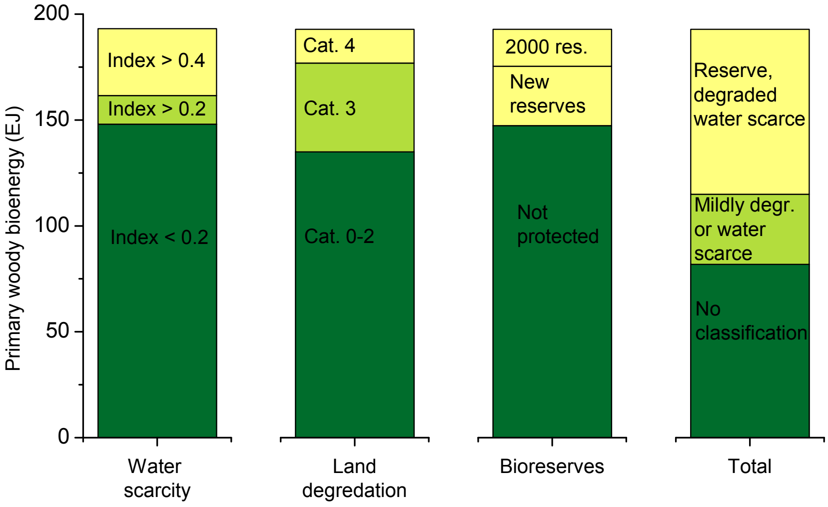

Figure 3.3.5: Impacts of sensitivity analysis on 2050 potential for woody biofuels

Degraded areas

Degraded areas form an important topic in the discussion on bio-energy for 2 reasons:

- First, while abandoned agriculture areas are mentioned as a source for land for bio-energy, some of these areas are likely to suffer from land degradation. In fact, dependent on the degree of the degradation the soil might lose its function for biomass production or its

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[1] The Water Stress Indicator (WSI) is defined as the total actual water withdrawal as proportion of the maximum available runoff minus environmental water requirements

function as substrate for natural vegetation. Reclamation of degraded soils into suitable land for production or into natural vegetation can be difficult.

- For less severely degraded areas, some people argue that by using these areas extensively (for bio-energy production), it is possible to enhance soil recovery. In this case, these areas would be prime expansion areas with little biodiversity impact as original vegetation cannot automatically recover. Whether this is actually possible needs to be looked into further, but using degraded land for production might need considerable inputs and investments, but also might lead to benefits in view of recovery, biodiversity and biomass production.

In order to estimate the impact of degraded land use on biomass potentials roughly, data from the GLASOD database have been used in IMAGE. The GLASOD database has classified land world-wide in terms of soil degradation. Two main criteria were used: 1) the severity of degradation (category 1-4) and degree of degradation (0-100%). Next, these 2 axes for various degradation types have been combined into one final score again going from cat.1 to cat. 4.[2] Using the GLASOD maps of soil degradation, we have identified 3 categories of degradation: 1) no to minor degradation, 2) serious degradation (GLASOD cat. 3) and 3) severe degradation (GLASOD cat. 4). We assume that the last category is too severely degraded to include in bio-energy potentials because it will not be feasible in practice due to high costs, while the second category could potentially include useful areas to target to combine soil restoration and bio-energy production. As much more analysis is required to assess the whether such combination is possible, the overlay made here should be regarded as indicative. No assumptions have been made on lower yields and/or higher costs of exploitation.

The results show that biomass potentials would be about 8% higher in the DV-2 scenario if severely degraded land areas could be used. Another 22% could be gained in modestly degraded areas.

Biodiversity/nature reserves

Another important relationship exists between conservation of biodiversity and bio-energy use. It should be noted that already in all calculations so-far forest areas and 50% of natural grasslands have excluded for reasons of biodiversity conservation. However, also outside these areas bio-energy use could lead to a reduction of biodiversity. In order to provide some insight into this, we have used maps of 1) nature reserves in the year 2000 and 2) areas designated to become nature reserves under the Sustainability First scenario of the Global Environmental Outlook of UNEP. Under this scenario, most of the biodiversity hot-spots are brought under protection – while the scenario also aims to protect sufficient areas of different eco-regions. Impacts of bio-energy potential is considerable. Excluding 2000 reserve areas reduces the total bio-energy potential by around 10% - while excluding the (very ambitious) expansion of reserves by 2050 would reduce the potential by another 15%. In total, this may lead to a reduction of bio-energy potential by 25%.

Integration

In Figure 3.3.5, we also show the combined impact of protected areas, degraded land and water availability in sensitivity analysis (last column). As indicated, a considerable part of the original potential either in severely water scarce areas, in areas with severe land degradation or in potential nature reserve areas. This part of the potential, i.e. 40%, may be considered as not available. A second category is either found on soils with mild degradation or in areas with mild water stress. The question whether this part of the total potential (20%) can be used (or even maybe an attractive area to use, see soil degradation) remains open. Note, however, that the

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[2] Light degradation of soils means that there is a somewhat reduced productivity of the terrain and moderate degradation of soils requires major improvements often beyond the means of the local farmers. Strongly degraded soils are not reclaimable at farm level for food production and are virtually lost. Extremely degraded soils are considered irreclaimable and beyond restoration. The strongly and extremely degraded soils together cover about 300 million ha. The total area of degraded soils is about 1964 million ha, which is about 15% of the total land surface. The four main types of soil degradation, in order of importance, are water erosion (56%), wind erosion (38%), chemical deterioration (12%) and physical deterioration (4%). The degradation is in almost all cases human induced.

potential agricultural efficiency increases as presented in Figure 3.3.2 are not included in this sensitivity analysis; see Figure 3.3.6.

Figure 3.3.6 summarizes the findings of the analysis in a different way by showing the 2020 and 2050 total potential for biofuels and electric power using a crop mix that leads to maximal potentials for the production of biofuels or electric power. Results are given in terms of primary (before conversion) and secondary energy content after conversion: the actual energy produced in the form of biofuels or electric power. In each case, the first column indicates the most optimistic estimate for potential assessed here assuming the compact agriculture case and the 12.5% increase in yields for bio-energy crops. The second column shows the potential under the default DV-2 case and finally the third column indicates the potential after conversion. For each column, the white area indicates the part of the potential that might be excluded as it is either 1) severely degraded, 2) under severe water stress or 3) potential nature reserve, while the green area indicates the remaining potential. The total potential for biofuels slightly exceeds that of electric power as here in some cases more productive crops are used (sugar; selection on lowest production costs).

For the DV2 scenario the remaining primary potential for bio-energy varies in 2020 somewhere around 70-100 EJ (for power and transport) and in 2050 somewhere around 100-175 EJ. Using more optimistic assumptions for development of agricultural yields, these number change into around 75-125 EJ in 2020 and around 200-275 EJ in 2050.

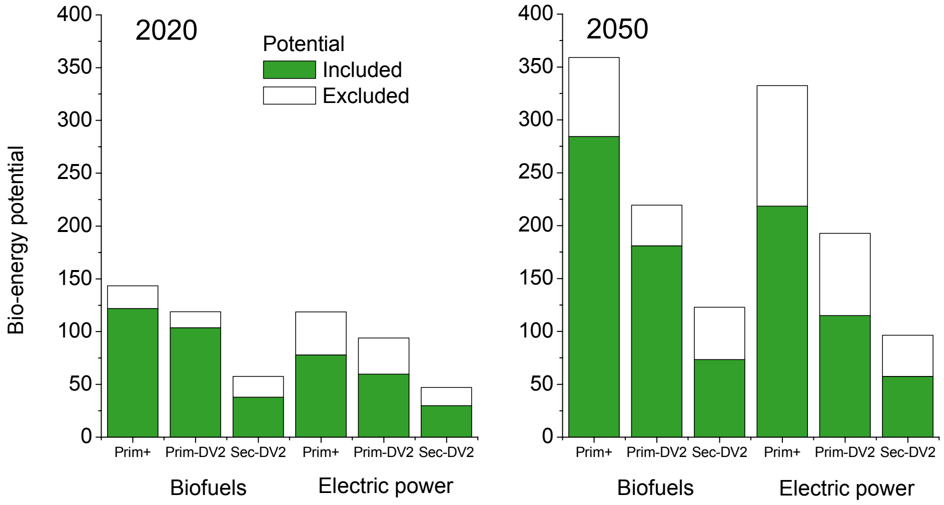

Figure 3.3.5: Potential for bio-energy, primary and secondary. Included means including uncertainties (i.e. soils with mild degradation or areas with mild water stress)leading to lower potentials (Note that the potential for biofuels and electric power are mutually exclusive; they cannot be added up)

A final factor that determines the use of bio-energy is costs. On the basis of additional assumptions on capital and labour costs for production and conversion of bio-energy and transport costs – it is also possible to estimate the costs curves for both biofuels and (bio) electric power. The curves move out over time (as potential increases) and come down over time (as a result of technology progress on costs). The curves assessed on the basis of the information presented here are shown as Figure 3.3.7. These curves can be compared to the information discussed in Section 3.2.

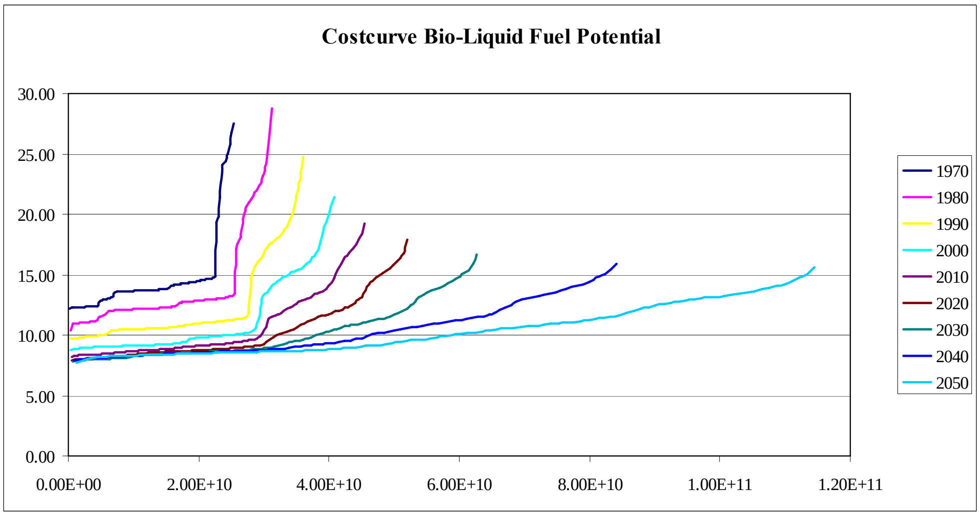

Figure 3.3.6: Cost curves for biofuels (graph needs to be updated-units?)

3.4 Biodiversity consequences of bio-energy use

From a biodiversity point of view (as expressed in CBD and IPCC goals), the effects of growing bio-energy crops are the response to several (global) environmental developments. On the short term, land-use dynamics are dominant, while on the long term the contribution to reducing climate change becomes important. Assessing both opposite effects of bio-energy is surrounded with considerable uncertainty, and is influenced by many other modelling exercises involved in. For instance, projecting climate change will set the required mitigation efforts, while estimating the biomass potential in mitigation will determine land-use.

A complete sensitivity and uncertainty assessment should ideally consider: uncertainty in definitions (using different indicators), data uncertainty (land use data), model parameter uncertainty (responses of climate change and other pressures), conceptual model uncertainty, and scenario assumptions. Only a few sources of uncertainty could be investigated, and are presented as first order estimates of possible effects of scenario choices and model sensitivities.

The OECD scenario for the Environmental Outlook (OECD, in prep) serves as a background for this exercise. In the OECD baseline scenario, biodiversity declines by 11% between 2000 and 2050 (expressed in MSA). For an ambitious 450-ppm option for climate change mitigation, large scale bio-energy production is implemented with mainly woody biofuels. For this, 1.8 million km2 of abandoned agricultural land is used, and a further 3 million km2 of extensively used grasslands (considered having a semi-natural character) are converted. Compared to the baseline, the total biodiversity decline in the option is 1% less (relative difference of 10%).

Local biodiversity of different crops
Important for the local biodiversity of production areas are the specific crop types used, and the type of land allocated for biofuel production. Three different hypothetical cases can be compared: using converted natural areas, using abandoned agricultural areas, or using agricultural areas. The resulting differences of several percentages at most are relevant compared to the complete 450-ppm option effect of ± 1% (see Table 3.4.1).

1- Growing bio-energy crops on natural areas (converted forests and natural grasslands) will lead to large biodiversity losses. Agricultural crops lead to a loss of - 3.1%, woody biofuels to -2.7%, and agro-forestry systems to -1.8%.
2- Using abandoned areas will lead to lower local biodiversity losses. We assume that these areas would be otherwise be used for nature restoration (leading to partially recovered

nature in 2050). Using these abandoned areas will then lead to losses of -1.3% for agricultural bio-energy crops, -0.9% for woody biofuels, and no net loss for agro-forestry. In the OECD climate change option, a large part of bio-energy production is allocated on extensively used semi-natural grasslands. These grasslands may contain valuable biodiversity, as is the case for European High Nature Value farmlands (mostly grasslands) that are important for conserving agro-biodiversity. Temperate grasslands present a category that is underrepresented and falls short of the 10% target for global Protected Areas (IUCN and UNEP-WCMC, 2003). More knowledge on the global extent and biodiversity status of extensive grasslands, and their attractiveness for biofuel production is needed to better assess this subject.

3- Agricultural areas contain a relatively low local (residual) biodiversity. Replacing these crops with woody biofuels leads to a local biodiversity increase of +0,5%, and using mixed land-use systems (agro-forestry) leads to an increase of +1,4%. However, this local biodiversity effect neglects the possible shift in production area for food production. The total effects of land-use dynamics on a global level will therefore be different.

The mean MSA values for different land-use categories are sufficiently known for application in global land-use assessment, but there is considerable variation in values between individual studies. These can be the result of for instance different time scales (years after conversion), landscape structure and specific management. A further analysis on these sources of variation can possibly give insights into (local) practices that are favourable for combining biodiversity and human use at local scales.

For these exercises, a constant area for bio-energy production is taken for comparative reasons. This leaves the specific contribution of crops to reducing atmospheric carbon out of consideration that will determine the required area for the different crops. Further, when agricultural and abandoned areas are used, shifts in food production regions can be expected and consequently further biodiversity losses. The exact effect of different crops and allocation can only be investigated by global and integral modelling exercises.

Uncertainty in the climate change response

Different model concepts and indicators may give different results for future effects of climate change on biodiversity. For instance, the MSA indicator presents changes in local species abundance. Other often used indicators focus on the risk of ultimate species extinction (IPCC WGII, 2007). Different outcomes will not easily converge with more research, but must be seen as complementary information on the complexity of the biodiversity issue, and the mechanisms underlying biodiversity change.

The GLOBIO implementation of stable areas with suitable environmental conditions shows relatively little variation in the calculated parameters. More variation can be found in different climate models that give future environmental conditions, and in the sensitivity of the climate system to rising atmospheric CO2-eq concentrations. With extreme values for climate sensitivity and assuming linear responses of biodiversity, a biodiversity response from -1.8% to -4.5% is estimated (see Table 3.4.1). This range in values is comparable to the values found for the different crop types and land allocation, discussed above.

In integral models, several different global developments take place simultaneously. This makes it hard to exactly assess the effect of biofuels alone and the factors that may tip the balance between losses and gains. The bio-energy effects can be better assessed by implementing hypothetical scenarios, varying the implementation of biofuels only. Assuming linear responses between emission reductions and biodiversity effects, a first exercise shows that the total balance between land-use changes and climate change effects will probably be negative (total effect of -0.8% to -1.4%). In the 450-ppm options, the reduced climate change effects are the result of a complete package of mitigation measures, while woody biofuels are responsible for about a third of the effect.

Including species-richness in the MSA indicator

An important characteristic of the MSA approach is the integration of different impacts in one and the same indicator, and the possibility to aggregate the biodiversity values over countries and regions. This allows comparing and balancing different pressures and time scales. As a consequence of this approach, MSA is not sensitive to all aspects of biodiversity. It is not sensitive to the species richness of different biomes, and all different ecosystem types (whether species rich or poor) are treated equally.

To explore the possibilities of including species richness in the indicator, the usual are weighing was complemented by species weighing. This was done by using species richness numbers compiled for each distinguished eco-region (64 in total ; WWF 2006). The species weighted MSA accentuates species rich regions, such as Latin-America, Africa and parts of Asia. The global biodiversity decline for the OECD baseline is now somewhat larger (-1%). However, the same happens in the 450-ppm option, and the net result hardly differs from the usual MSA.

Conclusions

With the presented and discussed sources of uncertainties and assumptions, a limited range of sensitivities was presented for the IMAGE-GLOBIO approach for assessing biofuel effects.

Ultimately, the effects are determined by the balance between land-use changes and climate change effects. Specific used crop types and land-use dynamics exert an important influence on this net outcome. Using still natural areas obviously leads to the highest losses, while using abandoned lands might reduce this loss. Using agricultural areas gives the lowest local impacts, but neglects shifts to other food production regions. The most important scenario uncertainty lies in the assumptions on agricultural land-use versus abandoned and converted land use. Biodiversity responses to climate change remains a subject for further investigation, but will undoubtedly give different results, depending on the models and concepts used.

The exact conditions under which abandoned areas will be available for biofuel production remain a matter of discussion. Trade and cost mechanisms usually determine the regional allocation of abandoned and natural areas. As such, land abandonment is independent from biofuel production, stimulated by liberalization and differences in regional production costs. But bio-energy production can also be considered as a stimulating factor through land competition.

Making a balance between global land-use changes and climate responses must be done by integral modelling, as the specific crop potentials determine the required area for biofuels and the contribution to reduced atmospheric CO2 concentrations. Including both elements (land-use changes and CO2 reduction) in one Life-Cycle-Analysis type of indicator may prove useful to summarize the balance. A first estimation of this net biofuel effects, separated from other scenario developments, indicates that the biodiversity loss through land-use change is larger than the reduced climate change effects, brought about by bio-energy production alone.

Table 3.4.1 First order sensitivities of varying several assumptions and sources of uncertainty. At the top, possible ranges in biodiversity effects of growing bio-energy crops are given, for extreme land-use variants. The GBO2 and OECD 2007 scenarios are taken as a background for the projected area for bio-energy production. Biodiversity values for this area depend on the assumed land-cover (natural, abandoned and recovered, agricultural). Next, the additional loss or gain is given for different cropping systems.
At the bottom, extremes in climate change mitigation effects are given, based on uncertainty in climate sensitivity only.

	GBO2 study	**OECD study**	**Unit and remarks**	
BASELINE information				
Biodiversity in 2000	70%	73%	Global MSA	Different methods and data used
Baseline biodiversity decline	- 7.5%	- 11%	Global MSA	
OPTION information				
Option biodiversity effect	- 1%	+ 1%	Global MSA	
“Biofuel area”: used for woody biofuel production in the 450-ppm option	6	4.7	million km2	primary (bio-)energy : 150-EJ and 130-EJ (23% and 20% of global energy use)
Different biofuel crops: extreme variants and local biodiversity effects				
Potential biodiversity in natural area	4.6%	3.6%	Local MSA	“at stake” when all natural areas are used
- 1st generation biofuel crops	- 4.0%	- 3.1%		
- woody biofuels	- 3.4%	- 2.7%		
- agro-forestry	- 2.3%	- 1.8%		
Potential biodiversity in abandoned lands (50 years recovery)	2.3%	1.8%	Local MSA	“at stake” in partly recovered areas
- 1st generation biofuel crops	- 1.7%	- 1.3%		
- woody biofuels	- 1.1%	- 0.9%		
- agro-forestry	no change	no change		
Residual biodiversity in agricultural areas	0.6%	0.4%	Local MSA	assuming all used area is in agricultural use
- 1st generation biofuel crops	no change	no change		
- woody biofuels	+ 0.6%	+ 0.5%		
- agro-forestry	+ 1.7%	+ 1.4%		
Biodiversity response to different climate change sensitivities (ΔT in 2100 as response to 2xCO_2-eq)				Assuming linear responses of biodiversity
1.5 K	- 1,8%	- 1,8%	Global MSA	
2 K	- 3,0%	- 3,0%	Global MSA	
4.5 K	- 4,5%	- 4,5%	Global MSA	

3.5 The economic link between food, feed and fuel

In this section recent results of the Scenar2020 and the EU-RURALIS projects are presented that deal with the economic linkages between food, feed and fuel. The Scenar2020 project (Nowicki et al. 2007) identifies the tightness of oil/energy markets as a major uncertainty with regard to all conclusions concerning the future of agricultural markets and rural areas. Therefore the impact of biofuels may be under-estimated. They find, by using exogenous shifters in a partial equilibrium EU model called ESIM, that meeting 10% of EU energy requirements for transport in 2010 could take up 43% of current land use for cereals, oilseeds, set aside and sugar beet. The 5.75% objective for 2010 in itself will require 15.03 Mt of biofuels. If the feedstocks are all grown domestically, this would be equivalent to 12.02 Mha, or 9.4% of EU-25 agricultural land demand. It is projected, however, that in 2010 there will be only 6.98 Mha of agricultural land used to produce biofuels feedstocks, which is equivalent to 8.74 Mt of biofuels, 58% of total biofuels used and 5.5% of total agricultural land demand. A corollary of the increased demand for biofuels is the increased resort to bio-based materials (partially motivated to replace plastics, a petroleum derivative); the conjunction between the demand for biofuels and the demand for bio-based materials is likely to create competition with other demands for agricultural commodities.

EU-RURALIS is focused on the EU-situation and assesses the biofuel policy. First results are published in Wageningen UR and Netherlands Environmental Assessment Agency, 2007). Within the EU-RURALIS project (Version II) the GTAP model has been extended to analyze world wide expansion in the production of biofuels. The reference scenario assumes no mandatory blending for biofuel use. However it is important to notice that due to changes in relative prices (biofuel crops vs. fossil fuel) the use of biofuels also changes under the reference scenario even without a mandatory blending. The consequences of the EU biofuel directive on land demand and agricultural production within the EU and outside Europe are illustrated in Figure 3.5.1.

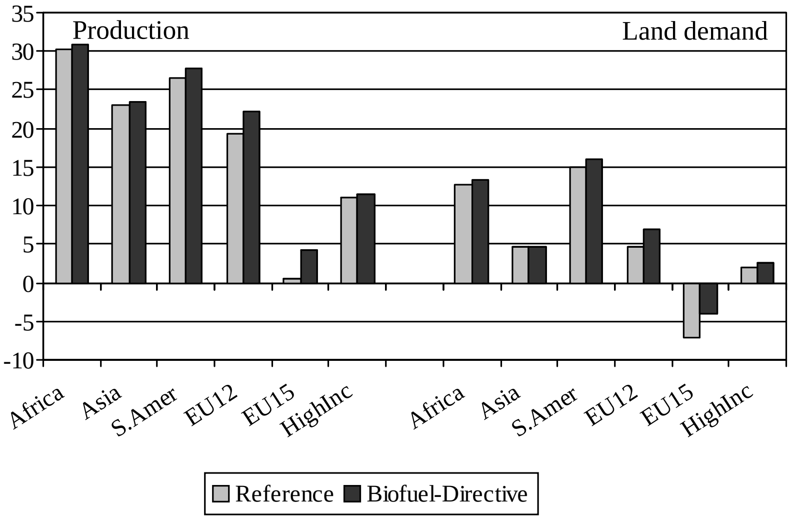

Figure 3.5.1 Impact of EU Biofuel Directive on Agricultural Land Demand and Production, 2010, change in percent relative to initial situation (2001)

The EU-biofuel directive has a strong impact on the agricultural production and land use not only in Europe (EU15 and EU12) but also to countries outside Europe. Especially in Central and South America the agricultural production will increase due to the additional demand for biofuel crops in Europe.

3.6 Greenhouse gas balances

Reducing greenhouse gas (GHG) emissions is a major driver for using biomass for energy and materials and many studies deal with GHG balances of biomass production and uses. Here, a couple of review studies that analysed a large number of GHG balances of biofuels and their main results are discussed. (Larson, 2006; Quirin et al., 2004, WWI, 2006; JRC, 2007). It should be noted, however, that only very few studies on biofuel production in developing countries exist.

The main results of these reviews is that in most biofuel chains turn out to reduce net GHG emission compared to their fossil counter-parts on a life-cycle basis with few exception found in the studies reviewed. The net results on GHG emission reduction in the analyzed studies, however vary broadly due to variations in methods and input data (e.g. rate of N_2O emissions) and due to differences in the performance of different biofuel chains (see also Figure 3.6.1) Most important aspects determining the GHG balances due to differences in biofuel chains are:

- Productivity of crop production (including fertilizer use)
- Efficiency of biomass conversion (including biomass use for process energy)
- Use of by-products and residues (allocation of the emissions)
- land use changes (leading to changes in the carbon content)

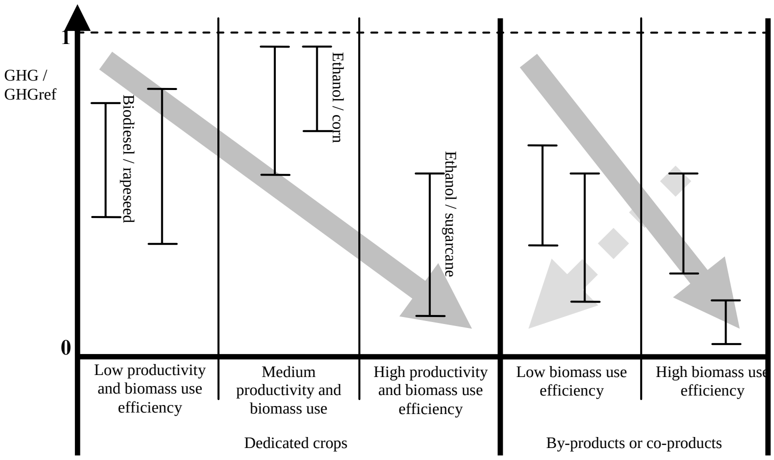

Figure 3.6.1: GHG effectiveness of different bioenergy systems. (B. Schlamadinger, Johanneum research, personal communication)

Productivity of crop production

Crop yields are an important factor for the evaluation of GHG balances, especially if compared on a per hectare basis; see for example Figure 3.6.2 and Table 3.6.1. Clearly crop yields depend on the type of crop produced and perennial crops often have higher yields than annual grain and seed crops. Moreover, crop yields and GHG balances also depend on the agricultural input - e.g. diesel and fertilizer, which are typically higher for conventional agricultural crops than for perennial lignocellulosic crops. It should be noted, that crop yields also depends on climatic conditions as well as on soil quality and that, therefore, GHG balances are location dependent.

Efficiency of biomass conversion

Clearly efficiency of biomass conversion also plays a role in the differences between lignocellulosic crops annual seed and grain crops as presented e.g. in Figure 3.6.2 and Table 3.6.1. Even though the conversion efficiency of biomass to 1st generation biofuels is currently higher than the conversion efficiency of lignocellulosics to 2nd generation biofuels, Larson et al., 2005 argues that efficiency increases in the development of 2nd generation conversion technologies will lead to overall higher GHG emission reduction potential of biofuels based on lignocellulosic crops. It should be noted the emission reduction is strongly dependent on the use of biomass for heat and electricity in the conversion processes

Concerning other uses for biomass, it should be noted that cascading of biomass, i.e. the use of biomaterials and waste-to-energy conversion can be favorable to the single energy use of biomass; see e.g. Dornburg et al., 2006. Comparing net GHG reduction of bioelectricity to biofuels depends strongly on the alternative energy source that is replaced. (JRC, 2007), however indicates that net GHG emission reductions of bioelectricity replacing electricity from natural gas or coal are about 2-5 times higher than reductions of bioethanol, but are in the range of than biofuels from wood gasification.

Use of by-products and residues

The use of by-products in the bio-energy production chain and the way they are accounted has an important impact on the overall GHG balances of bioenergy chain (Larson, 2006; Quirin et al., 2004, WWI, 2006; JRC, 2007). A high positive impact on the GHG balance is achieved when the by-product is used for an application reducing considerable GHG emissions and these reductions are credited for, e.g. if glycerine as a by-product from biodiesel production replaces synthetically produced glycerine. Also if a high amount of emissions of the bioenergy production chain is allocated to by-products, a positive effect on GHG balances occurs. For example, Wang et al., 2005 shows that for ethanol production from corn, emissions of the ethanol chain decrease by up to 52% due to emission allocation, while crediting by-product use would only lead to reductions of about 16%

Another important issue is the use of residues from agriculture, forestry and processing for bioenergy production. In this case, GHG emission of producing these residues can often be allocated to the main product of which the biomass is a residue of and the use of these types then leads to large net reduction of GHG emissions. However, it has to be taken into account that these residues often have alternative uses – if not used for energy – and that these uses have to be accounted for in GHG balances leading to less GHG emissions reduction in the whole chain.

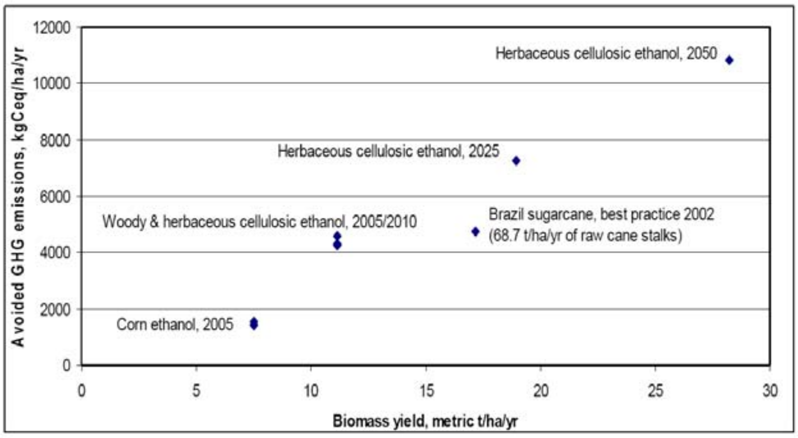

Figure 3.6.2. Avoided GHG emissions per hectare per year as a function of biomass yield for different routes to bioethanol production. (Larson et al., 2006)

Table 3.6.1: Estimated Change in Life-Cycle Greenhouse Gas Emissions per Kilometer Traveled by Replacing Gasoline with Ethanol from different feedstock (WWI, 2006)

Feedstock (country or other specifics, where available)	**Emissions Change (percent)**	**Source**	**Feedstock (country or other specifics, where available)**	**Emissions Change (percent)**	**Source**
Corn			**Wheat**		
E10 (U.S.)	-1	M. Wang et al. (1999)	E100	-19	European Comm. (1994)
E10 (China)	-3.9	M. Wang et al. (2005)	E100	-32 to -35	Levy (1993)
E85 (U.S.)	-14 to -19	M. Wang et al. (1999)	E100	-45	Wuppertal (2005)
E85 (China)	-25	G. Wang et al. (2005)	E100	-47	Gover et al. (1996)

E90 (U.S., 2010)	*+3.3*	Delucchi (2005)
E95 (U.S., 1999)	-19 to -25	M. Wang et al. (1999)
E100	-13	Farrell et al. (2006)
E100	-21	Marland et al. (1991)
E100 (wet-milled)	-25	M. Wang (2001)
E100	-30 to -33	Levy (1993)
E100 (dry-milled)	-32	M.Wang (2001)
E100	-38	Levelton (2000)
Sugar Cane (Brazil)	-87 to -96	Macedo et al. (2004)
Wheat residue	-57	Levelton (2000)
Corn residue	-61	Levelton (2000)
Hay	-68	Levelton (2000)
Crop residue	-82	GM et al. (2002)
Wood	-51	GM et al. (2002)
Poplar tree	-107	Wang (2001)
Waste wood (Australia)	-81	Beer et al. (2001)
E100 (UK)	-47	Armstrong et al. (2002)
Sugar Beet		
E100	-35 to -56	Levy (1993)
E100 (N. France)	-35 to -56	Armstrong et al. (2002)
E100	-41	GM et al. (2002)
E100	-50	European Comm. (1994)
E100	-56	Wuppertal (2005)
Molasses		
E10 (Australia)	-1 to -3	Beer et al. (2001)
E85 (Australia)	-24 to -51	Beer et al. (2001)
Grass		
	-37.2	Delucchi (2005)
	-66 to -71	GM et al. (2001)
	-71	Levelton (2000)
	-73	Wang (2001)

Land use changes

GHG emissions and sequestration that are due to land use changes can play a major role in the overall GHG balance of biofuels (WWI, 2006), but are not accounted for in many LCA studies regarding GHG emissions of bio-energy chains. Research on GHG balances of for example palm oil has shown that changing forests or wetland to biomass plantations in general has a very negative impact on GHG emissions leading to net GHG emissions of the biomass chain. On the other hand, using degraded land and planting palm oil can lead to a net sequestration of carbon. (Wicke et al., 2007)

4 Discussion

From a review of recent literature (Section 2), several main issues evolved that influence the amount of biomass that will be available for energy and materials. For some of these issues ranges of biomass potentials had been analysed by means of scenario analysis in the studies reviewed. Furthermore, an indicative analysis of some of these main issues and their linkage to bio-energy potentials has been carried out using several energy demand and economic models (MARKAL, TIMER, IMAGE, LEI-GTAP) (Section 3). The issues analysed where those that are relatively easy to integrate (even though on a rough level).

Section 4.1 summarizes and discusses the uncertainties that have been investigated in an integrated modelling approach in Section 3, while Section 4.2 recapitulates those issues from the literature review that could not be further analysed. Finally, in Section 4.3 an overview of main uncertainties is presented and section 4.4 summarizes knowledge and knowledge gaps around biomass potentials.

4.1 Issues covered in quantitative analyses in Section 3

Improvement agricultural management

Yields for food and energy crops as well as animal production system are a key issue in determining biomass potentials. For example Smeets et al. 2007 has shown that depending on different agricultural management systems that are medium to highly efficient, the potentials for bioenergy crops vary from 200-1400 EJ/yr. Modelling in Image has shown that increasing yield levels of food and energy crops by about 12.5% and bringing 2050 technology levels in developing countries close to current Western European levels, leads to an increase of 40-60% of biomass potentials in the DV-2 scenario, respectively. For comparison, global average increase in cereal yields between 1961 and 1998 was about 2.2%/yr (FAOSTAT).[3] An important aspect of improving agricultural management is the rate of deployment of more efficient agricultural management practices in the developing countries, which itself depends on many factors that are often included in scenario analysis, such as socio-economic developments, policies, resource endowment, infrastructure, power, etc

Choice of crops

As yields, agricultural inputs and suitability of different types of climate and soil can be very different for different crops, the choice of energy crop is very important for overall biomass potentials. In this context, the developments in biofuels are crucial. Most recent studies assume the use of perennial lignocellulosic energy crops that can be used for heat and power applications, 2nd generation biofuels, but not for 1st generation biofuels for which sugar, starch and oilseed crops are required.

Perennial lignocellulosic crops, such as herbaceous and woody crops usually have higher total energy yields than annual starch, sugar and oilseed crops. The amount of biofuel that can be gained from these annual crops via 1st generation processes from 1 hectare is typically lower than the amount of biofuel that can be gained from lignocellulosic crops via 2nd generation processes. However, once 2nd generation technologies become commercially available, also lignocellulosic agricultural residues of annual starch, sugar and oilseed crops can be used for biofuel production. Another advantage of lignocellulosic crops is the fact that they are usually better suited to marginal lands (i.e. lands on which crop yields are very low) than annual crops. However, some of these marginal lands might not be suited to biomass production at all. It should be noted, that some perennial crops that are suited to the production of 1st generation biofuels such as sugar cane and palm oil have rather high yields, too. For example, in an analysis of the DV-2 scenario in IMAGE the global potential of sugar cane on abandoned land in

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[3] Extrapolating this global average rate of learning until 2050 would lead to an increase by a factor 2.5, while probably learning rates in developed countries that already learned a large part historically would be lower than in developing countries for which a large learning potential still exists.

2050 is about 60% of the potential of woody biomass, while for maize this potential is about 5% of the woody biomass potential, see Section 3.3. It should, however, be noted that data on crop yields in IMAGE is spatially not very explicit and that especially for maize potentials might be higher. Moreover, an optimal mix of crops on the available land might lead to higher overall potentials.

Bio-energy demand versus supply

Typically, supply and demand of biomass are investigated in separate models leading to estimates of geographical - what can be produced given land availability - and economic – what will be produced and used from an economic point of view - biomass potentials. Most studies on geographical biomass supply estimate only total amounts of available biomass, while some also analyse cost-supply curves of biomass. Dynamic adaptations of biomass supply to demand are, however, not considered in recent studies. Comparing scenario analysis of available biomass supplies with bioenergy demands shows that demands are typically lower than supply, even though the gap depends on the costs of biomass as well as on the assumption on global energy demand. In section 3.2, the global demand for biomass for the use for energy as modelled with TIMER is about 80-85% lower than the possible supply (Section 3.2). However, no result of integrated modelling supply and demand is available considering price effects. It should be noted that energy demand depends on cost-supply curves of biomass as well as learning in energy conversion, see below.

Use of degraded land for biomass production

An important question for the total biomass potentials and the availability of land is if and which degraded land areas (see Annex 4 for definitions) can be used for biomass production. Most recent studies include agricultural land without explicitly defining whether and what type of degraded agricultural land has been included. Hoogwijk et al. 2005 uses ‘low-productive lands’ which produce about 1-3% of the global potential for energy crops. In Section 3, the potential of using severely degraded land has been estimated to increase potentials by about 30%-45% compared to not using severely degraded lands.

This estimate has been made using soil quality and climate as a basis of yield estimates. It should be noted, however, that it is unknown whether the assumed yields are realistic as it is difficult to assess the impact of soil degradation on the productivity of the soil. This depends on many local conditions. In general one can conclude that yield levels on degraded soils are often far below the levels of the undisturbed soil.

Another issue in this context is the potential value of degraded lands for biodiversity. This value depends on whether and during which timeframe this land restores itself to pristine nature. Restoration of the original vegetation on degraded soils has problems similar to biomass production since most of the original conditions of the soil have been changed (lower nutrient levels, lower water holding capacity). However, it has been shown that taking biodiversity recovery into account presents a factor to consider for the net option effect in terms of biodiversity (Section 3.4)

Competition for water

The use of water for biomass production (rain-fed as well as irrigated production) competes with other industrial, domestic and agricultural uses. In general, the impacts of water availability on biomass potentials could be large as water use for industrial and domestic purposes as well as for agricultural food production is projected to increase strongly in the coming years. The evaluation of the potentials in Section 3 shows that water scarcity (as estimated in the WaterGAP model and not based on a river basin scale) decreases the area available for energy crops by 15-20% and decreases the estimated biomass potential by 15-25% compared to the DV-2 scenario. The increasing variability of rainfall due to climate change is expected to decrease the area further, while an increase in water use efficiency of agriculture (see below) and the use of perennial lignocellulosic crops (that might increase water retention in some areas) could increase the biomass potential based on water availability. However, the review of studies on water has shown that the demand and availability of water cannot be analyzed on an adequate scale to evaluate biomass potentials for regions with possible water scarcity. At least an analysis on a river basins scale is needed, but these data are not systematically available.

Learning in biomass conversion and competing technologies

The comparison of costs and efficiencies of biomass options with other options for energy supply is important for the use of fossil or biomass technologies for energy supply. This performance of energy conversion technologies can be influenced by 'technological learning', and cost-reducing effect that occurs more strongly in newer technologies, e.g. hydrogen fuel cells or biomass conversion, than in more conventional (fossil and renewable) technologies. The results in Section 3.2, assuming different rates of learning show that shares of bioenergy could vary strongly, but e.g. in a specific Markal run with overall faster learning rates for selected conversion technologies, the role of biobased options remains relatively unchanged.

Protected areas expansion

In current biomass potential studies, usually nature conservation areas are excluded from biomass potentials, but besides little or no land is reserved for biodiversity conservation. The issue which land can be used for biomass production without substantially decreasing biodiversity and nature conservation values and which land has to be excluded, has not been resolved completely. The analysis in Section 3 indicates that excluding existing nature reserves – even though part of these could legally be used for biomass production – and future nature reserves does decrease estimated biomass potentials by about 25%.

4.2 Issues not covered in the quantitative analyses in Section 3

Food demands and human diets

Assumptions on the future demand for food are crucial for estimating biomass potentials as in most studies it has been assumed that only land that is not needed for the production of food is available for biomass production, see also Berndes et al., 2003. Most estimates of biomass potentials that consider food demand and human diets are based on food demand projections of the FAO representing a large range of possible future demands depending on population developments and economic growth. Using these FAO projections, Smeets et al., 2007 estimates the difference between a scenario assuming low food demands and a scenario assuming high food demands while keeping other factors constant to be about 130 EJ/yr. Hoogwijk et al. 2005 estimates this difference to be about 50 EJ/yr.

Market mechanism food-feed-fuel

If the use of biomass as fuel or as feedstock increases, prices of agricultural land and food will increase in the short term in addition to autonomous price increased due to population and income growth. This effect influences in turn supply costs of biomass and subsequently economic potentials, but also has impacts on food security issues that are core of current biomass discussions. Some price effects have been calculated for 1st generation biomass crops. In Banse et al. (2007) world prices for 1st generation biofuel crops increase between 6.5% for cereals and 10% for sugar under a mandatory blending according to the EU Biofuels Directive. On the other hand the increase in biofuel use leads to a decline in crude oil prices by around 2%. Due to the fact that agricultural land is more or less a fixed factor, agriculture land prices react stronger on higher demand for biofuel crops as input for biofuel production. First result show that land prices in the EU increase strongly as a consequence of the biofuel directive. Land prices rise between 5% in The Netherlands and 15% in the UK.

Further analysis which takes also the impact of 2nd generation biofuel crops into account needs to be done to achieve a more profound analysis of the key variables for the driving forces behind agro-production which are related to market developments such as price changes, technical progress and policies.

Costs of biomass supply

The costs of biomass supplies are important for the amount of biomass that can be used economically, i.e. for the bioenergy demand. However, in energy demand models either static costs are used or cost-supply curves based on the availability of land after reserving land for other function. Hoogwijk et al. 2005 analysed using the latter method, the amount of energy crops available at prices below 2 Euro/GJ which is about the price of coal. This amount is about 30-40% lower than the overall technical potentials. Given the nature of biomass supply curves used, no price effects of competition between resources (biomass for materials, food, agricultural land, water, nature conservation) are taken into account in the cost-supply curves that determine energy demands, even though they are relevant for modelling.

Use of by-products from agriculture and forestry

By-products from food and wood production, e.g. lignocellulosic residues, and from their processing, e.g. rapeseed press cake, can be used for the production of bioenergy and for the production of animal feed. As second generation conversion technologies are able to cope with lignocellulosic by-products from agriculture and forestry, a wider range of sources for bioenergy becomes available increasing biomass potentials significantly (see also: choice of crops). Additional to this potential of energy crops, thus, a considerable amount of about 76-96 EJ of residues from forestry, agriculture and food and wood processing as well as secondary wastes are available at low costs. (Smeets et al., 2007) Moreover, in the discussion of competition between food, feed and fuel, the use of by-products as an animal feed has to be taken into account in order to assess the final effects on the feed market. This use of by-products potentially decrease the amount of biomass available.

Water use efficiency of crops

The water use efficiency of crops depends on the type of crops as well as on agricultural management. For example water use efficiencies in g biomass per kg of water are about 1.7-2.2 for wheat, 2.5-3.8 for sugar beet, 4.0-6.4 for sugar cane and 1-9.5 for lignocellulose crops (Berndes, 2002). Increasing water use efficiency of food crops as well as energy crops could reduce the competition for water resources between agricultural production and other uses, especially for irrigation type systems. This increased water efficiency might in turn lead to higher biomass potential. To determine this effect, quantitative research on the amount of biomass available in rain-fed and irrigated agriculture depending on water availability and realized water on a regional and global level would be needed. However, only studies on a field level addressing these issues are so far available.

Climate change

Climate change can influence the suitability of a certain area for biomass production as well as their 'biodiversity value', but limited research on the relationship between biodiversity, biomass production and future climate change has been carried out. The GBO2 (ref) study shows a negative effect of climate change on biomass production and biodiversity. These negative relations depend on the use of agricultural land that is not needed for food production and its restoration value as well as on the use on 'more natural' areas. However, a decrease in the possibilities of annual crop production might lead to larger possibilities for perennial energy crops. Research into these complex correlations and feedback mechanisms has not been sufficient to quantify the impact of climate change on biodiversity and biomass potentials.

Alternative protein chains

The production of proteins from animal farming uses large amounts of land and other resources. Life cycle assessment showed that a transition from animal to plant protein might result in a 3-4 fold lower requirement of agricultural land and about a 30-40 fold lower water use. (Aiking et al., 2006a) The land and water resources that could be made available by such a transition could then be (partly) used for biomass production and for relieving the pressure on biodiversity. The influence of changing protein sources for human consumption on biomass potentials could not be quantified within this study and has not been studied in the reviewed biomass potentials studies, but might be potentially large. An area of 25 million hectares of soy would yield an amount of protein equivalent to livestock presently fed by 400 million hectares of feed crops (300 Mha grains plus 100 Mha oilseeds), thus setting 375 Mha free (Aiking et al., 2006a). Changing protein sources requires technological change as well as a change of consumption patterns. Present trends, however, suggest meat demand to be increasing, rather than decreasing.

Demand for biomaterials [4]
Wood and fibre products (pulp, timber, boards, etc.) are the largest group of biomaterials that are currently produced. In studies considering all types of biomass resource, the demand for wood products is included, i.e. the wood products demand is subtracted from the future biomass potentials. Smeets et al. estimated the difference between high and low future demands for wood products in 2050 to be about 30 EJyr. Chemicals and other biomaterials might become another important area for biomaterial use and are usually not included in biomass potentials estimates. However, demands for biomaterials are comparatively low[5] and do not exclude the use of biomass for energy as cascading strategies, i.e. first using biomass for food, feed, materials and then converting organic wastes to energy, can be applied.

In energy demand models, the use of biomass as feedstock material is typically not included and the only global model that does take it into account predicts a limited, but not insignificant amount of biomass to be allocated to materials. As a consequence, coupling and integration of sector modeling (e.g. wood products, chemicals, forestry) to biomass potential estimates and is necessary.

GHG balances of biomass chains
The biomass potential studies regarded do include biomass options regardless of their greenhouse gas balance. GHG emission reduction is an important driver of biomass use and might increase actual biomass demands, while on the other hand excluding biomass chains with low or negative reductions could lower biomass potentials. However, the possible influence of this latter aspect is small, as most potential studies are already based on lignocellulosic biomass and, thus, disregard unfavourable biomass chains such as 1st generation fuels from annual crops and land use changes from wetland and forests to energy crop production.

4.3 Overview key uncertainties

In Table 4.4.1, the key uncertainties as discussed in the previous sections are summarized and evaluated in view of their importance (column 2). Also the impact on biomass potentials as estimated in the literature reviewed is presented (column 3). For example, for the improvement of agricultural management it is indicated that biomass potentials increase or decrease compared to the estimates in recent studies. This means that the reviewed biomass potential studies used different values for agricultural efficiency that are within the ranges that were derived from our review. As a consequence, biomass potentials estimated in the recent studies could increase or decrease if other assumption on agricultural management improvements would be assumed. On the other hand, for protected areas it is indicated that biomass potentials decrease compared to the ranges estimated in recent studies means, that if the recent studies would have included protected areas as has been discussed in this report the estimated potentials would be lower.

In addition to these results of the inventory, also the results of the integration phase from Section 3 are presented (column 4) and percentages of supply refer to the DV-2 scenario in IMAGE that estimates biomass potentials of about 200 EJ/yr. However, it should be noted that the results of the integration analysis provide an order of magnitude but are not based on an integrated modelling analysis.

Table 4.4.1 : Overview of uncertainties and their impact on biomass resource potentials

Issue/effect	Importance	Impact on biomass potentials

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[4] Even in this rough estimate, meat from grazing animals (beef, lamb, and goat) and from animals fed agricultural waste (pork) would be available still.

[5] For example results from a scenario analysis on bio-based chemicals indicate, that even in scenario with high market potentials of bio-based chemicals not more than 10% of agricultural land in the EU-25 in 2050 will be used for bulk chemical production - assuming lignocellulosic feedstock. (Patel, et al. 2006).

		compared to	
Supply potential of biomass		*supply as estimated in recent studies*	*DV-2 scenario in IMAGE*
Improvement agricultural management[1]	***	↑↓	↑ 40-65%
Choice of crops[2]	***	↓	↓ 5-60%
Food demands and human diet	***	↑↓	n/a
Use of degraded land[4]	***	↑↓	↑ ca. 30-45%
Competition for water [5]	***	↓	↓ 15-25%
Use of agricultural/forestry by-products	**	↑↓	n/a
Proceted area expansion [6]	**	↓	↓10-25%
Water use efficiency	**	↑	n/a
Climate change	**	↑↓	n/a
Alternative protein chains	**	↑	n/a
Demand for biomaterials	*	↑↓	n/a
GHG balances of biomass chains	*	↑↓	n/a
Demand potential of biomass		*demand as estimated in recent studies*	*biomass supply as estimated in TIMER*
Bio-energy demand versus supply[3]	**	↑↓	↓ 80-85%
Cost of biomass supply	**	↑↓	n/a
Learning in energy conversion	**	↑↓	n/a
Market mechanism food-feed-fuel	**	↑↓	n/a

Importance of the issues on the range of estimated biomass potentials: ***- large, ** - medium, * – small
Impact on biomass potentials. Potentials as estimated in recent studies would: ↑ - increase, ↓ - decrease, ↑↓ increase or decrease – if this aspect would be taken into account.
N/a: no quantitative analysis has been carried out in this study

[1] Increasing yield levels of food and energy crops by about 12.5% compared to the baseline (half the suggested improvement potential in the International Assessment of Agriculture Science and Technology Development leads to an increase of about 40% of biomass potentials in the analysis in Section 3. Moreover, bringing 2050 technology levels in developing countries close to current Western European levels leads to an increase of up to 60% of potentials in 2050.

[2] The default scenario in IMAGE assumes the production of woody biomass crops. An analysis of the biomass potentials on abandoned (i.e. not used for food production) agricultural land, results for sugar cane in about 60% of the potential for woody biomass, while for maize this values is only about 5%.

[3] The economic biomass potentials based on energy demand modelling is much smaller than the possible technical biomass supply. Starting from a biomass cost-supply curves with a maximum supply of 700 EJ/yr in 2050, the energy demand at carbon taxes of 0-300 €/tC is only about 15-20% of the possible supply, i.e. the economic potential is 80-85% lower than possible supply.

[4] In Section 3, the potential of using severely degraded land (cat. 3 and cat.4 of the GLASOD classification) has been estimated to increase potentials by about 30% (cat.3) and 45% (cat. 3 and 4).

[5] Other main use biomass production competes for water are agricultural, industrial and domestic uses. Excluding areas with a water scarcity of >0.4 and of >0.2, respectively, leads to a decrease of estimated biomass potentials of about 15-25% in the analysis in Section 3. However, due to climate change, in future the number of regions with water scarcity will increase and competition for water will become more important.

[6] Reserving nature reserves in 2000 areas designated to become nature reserves under the Sustainability First scenario of the Global Environmental Outlook of the UNEP leads to a reduction of up to 25% of biomass potentials.

4.4 Summary: what we know and don't know

In recent discussions about the large-scale development of biomass use for energy and materials, many issues around biomass potentials and linked areas such as water, biodiversity, food, energy demands and economic developments play an important role. Below a summary of knowledge and knowledge gaps concerning biomass potentials are given. Note that social impacts of biomass use and impact on energy security— though of large political relevance — have not been an explicit part of this study. Also policies and their effects on biomass potentials have only been analysed on a very limited level, i.e. investigating the effects of carbon taxes on energy demand.

1. Are biomass potentials sufficient to supply a large part of future energy demands?

In principle, biomass potentials are likely to be sufficient to allow biomass to play a significant role in the global energy supply system. Under the assumption that food demands of future population are met, most recent studies estimate global biomass potentials of 300 to 800 EJ/yr in 2050 for various scenario conditions. However, our own analysis showed that under negative circumstances concerning land availability - i.e. excluding large areas for nature protection, mildly to strong water scarce areas and mildly and severely degraded land from biomass production – only about 80 EJ/yr from energy crops might be available, while an additional amount of about 80 EJ/yr from residues and an additional amount about 60-100 EJ/yr of surplus forest growth is likely to be available. At the same time, scenario analyses predict a global primary energy use of about 600 – 1040 EJ/yr. (WEA, 2000) Energy demand models calculating the amount of biomass used if energy demands are supplied cost-efficiently at different carbon tax regimes, estimate that in 2050 about 50-250 EJ/yr of biomass are used, a range significantly lower than the estimated supply potential. For determining future economic potentials of bioenergy more exactly, however, an advanced integration of demand models with cost-supply curves of biomass and extended knowledge about technological learning in energy conversion technologies would be necessary.

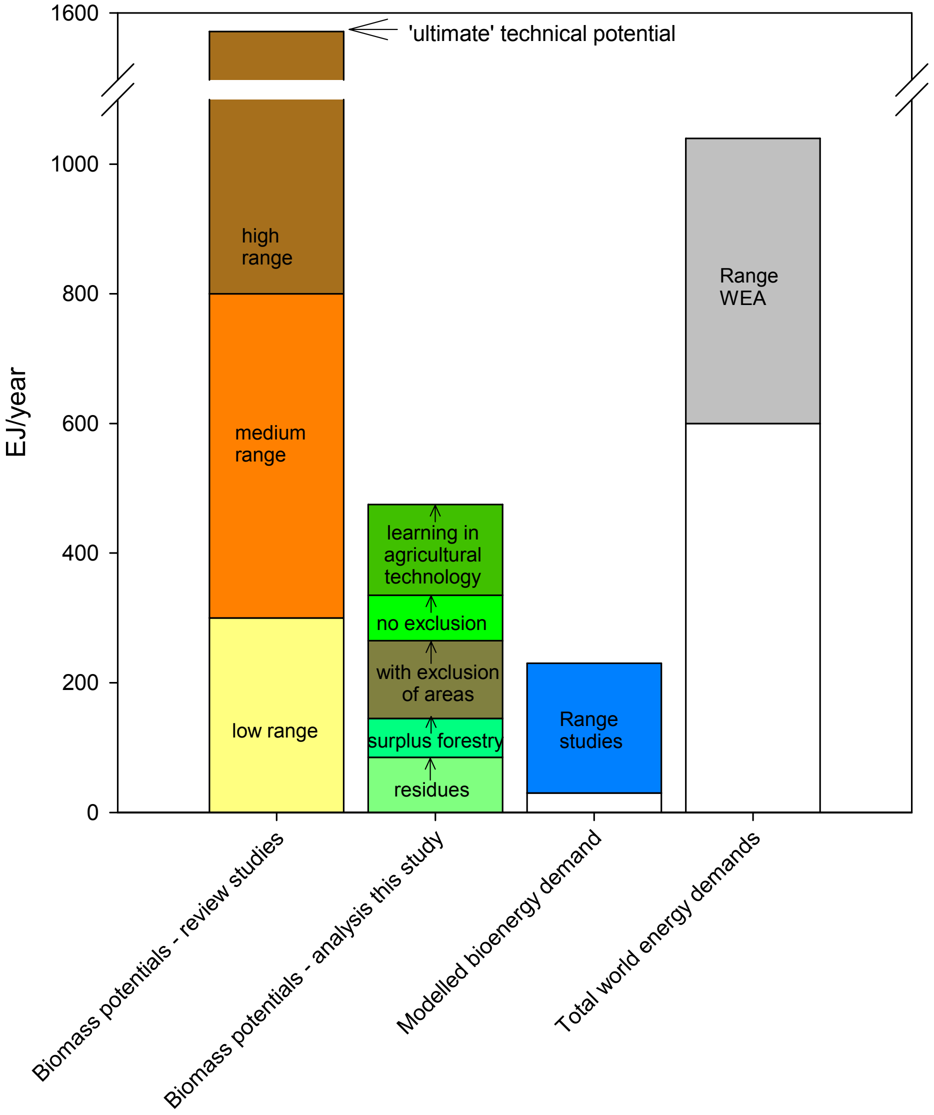


Figure 4.4.1: Comparison of technical biomass potentials with bioenergy demands in 2050. Biomass potentials as analysed in this study refer to the DV-2 scenario of IMAGE. (Exclusion of areas is the exclusion of mildly and severely degraded and water stressed areas as well as the exclusion of areas designated as current and future nature reserves, while learning in agricultural technology reaches levels as assumed in the SRES A1 scenario; see also Section 3.3.)

2. *What drives the economic competitive use of bioenergy and materials?*

Considering the economic part in the discussion of biofuels, most important is the fact that biofuels crops as an input to biofuel production such as cereals, oilseeds or sugar are in direct competition on the consumption side. For biomass such as willow or switchgrass this competition is less stringent. However, also in this case the biomass production is in direct competition for scarce resources, especially land. Changes in relative prices between different crops and between different energy sources, namely biofuel crops versus fossil energy, are the key drivers in future use of biomass. The economic analysis of biofuel use clearly shows that apart from direct policy measures, e.g. mandatory blending commitments, this price ratio is the most significant driver in the use of biofuels.

Any analysis of biofuel potentials which also takes economics into account must consider this key element. However, the dynamics are also important, because shifts in relative prices also trigger investments and technical progress in the biofuel sector which lowers in the long-term production costs and increases the long-term profitability of biofuel production.

3. What are the main sources of biomass?
Biomass for energy and material source in 2050 is derived from three major sources: (1) residues and waste (about 5-20%), (2) surplus forest growth (about 5-15%) and (3) energy crops (about 60-80%). In the biomass potential studies, it is assumed that biomass is grown on surplus agricultural land that is not needed for food production and partly on other types of land. This surplus land again depends on the demands for food and material and the subsequent price effects.

4. What role might degraded lands play in biomass production?
Another important question in determining future biomass potentials is whether degraded lands of which productive capacity has declined temporary or permanent, can be used for biomass production. At this moment the potential of the large area of degraded soils – classified as light and moderately degraded and covering about 10% of the total land area – to contribute to the production of biomass is not yet clearly assessed. This is because of the unknown impact of two possible drawbacks: firstly the enormous efforts and long time period required for the reclamation of degraded land and secondly the low productivity levels of these soils. In the integration analysis it has been shown that using severely degraded land would increase biomass potentials by about 30-45%, assumed that in principle it would be possible. However, using severely degraded land for annual crop production might require large investments and many attempts for reclaiming degraded land for food production have failed (ref). However, other attempts with e.g. reforestation and agro forestry might be more promising for biomass production and some projects in the past on e.g. saline soils have been successful (ref India). Further research on the potential of degraded soils for biomass production is needed. Preferably, other mitigation options (carbon storage in soils and vegetation) and adaptation options should be integrated in the research on the potential of degraded soils for biomass production.

5. What determines biomass yields
It should be noted that the conclusion that future biomass potentials are large enough to play a relevant role in supplying a significant part of future energy demands depends strongly on land availability (see above) and to a lesser extent on biomass yields which depend mainly on the development of agricultural management and the choice of crops. First, most recent biomass potentials studies assume that the efficiency of agricultural production improves in the coming decades assuming low to high technology development rates. (For illustration, extreme scenarios that assumed extensive agriculture or high advanced technologies with land-less animal production resulted in estimated future global biomass potentials of about 0 EJ/yr and 1500 EJ/yr, respectively.) Practice, however, shows that deployment of agricultural technologies in developing countries can be a difficult task and implementation strategies need to be studied very well. Second, all estimates of future biomass potentials discussed are based on the use of

perennial lignocellulosic biomass in 2050. This necessitates the availability of 2nd generation conversion technologies for the production of biofuels and most chemicals. Perennial lignocellulosic crops have in general higher yields than annual sugar, starch and oilseed crops, while tropical perennial sugar and oil crops have high yields in general, too. Calculations in the integration part of this study indicate that potentials for annual biomass crops, i.e. maize, might be very low and not sufficient to provide a larger parts of energy demands.

6. Is water a limiting factor for biomass potentials?

In general, water availability can be a limiting factor for the production of biomass and food. A simple and rough analysis in this study has shown that excluding water scarce areas decreases the biomass potentials by about 15-25% for woody bio-energy crops in 2050, in a scenario with biomass potentials about 200 EJ/yr (and thus excluding residues and learning in agricultural management). Water availability, however, has not been analyzed on a sufficient detailed spatial level to estimate regional biomass potentials in water scarce areas. Another remaining point of uncertainty is the possibility to increase water use efficiency in agriculture and as such increasing biomass potentials. A regional to local analysis is necessary to further evaluate this possibility. Finally, climate change will increase variability of rainfall patterns. It is expected that in the sub-tropics and some already water scarce areas rainfall will decrease, while at high latitudes is will increase. For the tropics estimates vary.

7. What is the relation between biodiversity conservation and using bioenergy?

Studies that estimate biomass potentials assume in general that nature conservation areas are excluded from biomass production. As such estimated biomass potentials consider biodiversity conservation on a base level. Assuming that larger parts of land should not be used for biomass production for reasons of biodiversity conservation, potentials would decrease accordingly. In most cases perennial lignocellulosic crops have lower impacts on biodiversity than annual sugar, starch and oilseed crops and are, thus, better suited for combining biodiversity and biomass production. Important open questions in this area are:

- to what degree potential energy production on a certain piece of land is related to the (potential) biodiversity value of the same piece of land if reserved for nature
- how to measure biodiversity, realizing different available indicators tell different stories
- what are the effects of future climate changes on biodiversity (very uncertain) and areas for biomass production (more certain)

8. What is the effect of biomass use on food prices?

Economic analyses indicate clearly that food prices increase with an increased demand for biomass, but the magnitude of this increase is uncertain. However, in the long term, price increases might accelerate agricultural efficiency leading to larger potentials of food and biomass mitigating price increases. For example, OECD and FAO project a price increase of coarse grains prices of about 30% in the short term and about 10-20% in the medium term of 2010-2016 compared to 1996 level. At the same time, prices of sugar are projected to increase about 30-40% and then even to decrease compared to 1996 level. (FAO-OECD, 2007) Only part of these projected price developments is due to the increase of biofuel production, while other parts are due to low recent harvests and increasing other demands. This analysis indicates clearly that land, food and energy demand are linked via prices. Thus, a priori not a certain area will be reserved for food production, but economic mechanisms determine the distribution of land uses. For annual crops that are used for the production of 1st generation biofuels, the linkage between food prices and biofuel demands is probably larger than perennial lignocellulosic crops used for 2nd generation biofuel production. This is due to direct competition. However, currently agricultural models do not include and analyze 2nd generation biofuels and knowledge on the impacts of 2nd generation biofuels on food prices is lacking. Finally, while large amounts of biomass can be used without jeopardizing future global food demands, it should be noted that food availability and affordability are very regional and that this future regional distributions of food and energy supplies are not sufficiently known, yet. Here, further knowledge including the influence of policies and subsidies on food security especially in developing countries is needed.

9. How should the available biomass be used?

Energy demand models show that the optimal use. in terms of cost-efficient energy supply depends on future technological development of bio-energy technologies as well as alternative technologies. Other major drivers found for directing biomass use are greenhouse gas reductions, carbon taxes and oil prices. Thus, cost-efficient optimal biomass use strongly depends on future developments. From a greenhouse gas perspective, 2nd generation biofuels are in most cases more efficient than 1st generation biofuels, while the comparison between 2nd generation biofuels and electricity depends on energy conversion technologies as well as fossil references for electricity production. Using biomass for materials, e.g. for construction and chemicals, and cascading of these materials can be attractive from a greenhouse gas reduction perspective. Compared to energy, however, markets for biomaterials are rather small.

10. What types of analyses are still needed?

This review gives and overview of the most important linkages between the arenas of water, food, biodiversity, economic effects, energy demands and biomass potentials. While knowledge and knowledge gaps in these areas have been discussed above an integrated analysis of these areas is still missing. Important issues in such an integrated analysis are:

- Drivers and barriers in the food-feed-fuel nexus that could be used to refine modelling and scenario analysis of geographical and economic biomass potentials
- Linkages between the availability and prices of water, the availability and prices of land, the demand for food and feedstock, the demand for energy and between the cost-supply curves of biomass
- Regional analysis that analyze the relation between food security, biomass potentials, water availability and land use changes on a spatially explicit level
- Mechanisms of changes and the implications of policy instruments in different parts of the world

5 Conclusions and recommendations

5.1 Main conclusions

Current understanding of the potential contribution of biomass to the future worlds' energy supply indicate that the total supplies could amount from a minimal 200 EJ up to 1500 EJ theoretical potential (compared to some 450 EJ current global primary energy demand). This assessment gave a much more sophisticated view on the factors and biomass resource categories that explain the ranges, which are especially caused by the way food demand and agricultural management develops and uncertainties to what extent more marginal and degraded lands may be deployed for biomass production. The potential consists of three main categories of biomass:

1. Residues from forestry and agriculture and organic waste, which in total represent between 40 - 170 EJ, with a mean estimate of around 100 EJ. This part of the potential biomass supplies is relatively certain, although competing applications may push the net availability for energy applications to the lower end of the range. The latter needs to be better understood, e.g. by means of improved models including economics of such applications.

2. Biomass produced via cropping systems on possible surplus good quality agricultural and pasture lands. This part of the potential biomass supplies is the most significant and can amount up to over 300 EJ for the high level improvement for agricultural efficiency included in the SRES scenario range. It is also a more uncertain category. The key factor determining net availability of land is improvement in efficiency in agriculture and livestock production systems. From a technical perspective, potential efficiency increases are very large seen on a global basis, especially in developing countries as is highlighted in the study of Smeets et al., 2007. However, the speed at which such improvements may be realized is uncertain and depends on a wide variety of factors which are partly poorly understood and manageable. In particular the economic drivers for such developments require further attention. The lower estimate given in this study based on the DV-2 (or OECD) scenario results in biomass supplies up to 80 EJ (which includes corrections for water scarcity, land degradation and new land claims for nature reserves; see also the third category below). A 'compact agriculture scenario' (about similar to the A1 and B1 SRES scenario's) would add some 150 EJ to that estimated 80 EJ, resulting in a range of 80 – 230 EJ.

3. The use of marginal and degraded lands that are not used for food production. This aspect is addressed in some more detail in this assessment. Although it should be recognized that data quality on such soils is fairly weak, land-use scenario's in this respect are crude and that knowledge to what extent different types of vegetation can be established has seen limited study, some global estimates have been compiled. The potential contribution could amount up to 150 EJ, but this would include a large area where water scarcity provides limitations and soil degradation is more severe. The lower estimate, covering more limited degradation and water scarcity represents and estimated 50 EJ. This lower estimate also incorporates estimated additional demand for new nature reserves.
The key uncertainties for this category are the extent to which such lands can really be utilized for biomass production from a technical and economic perspective and to what extent nature and biodiversity conservation may conflict with the, partial, use for biomass harvesting, since marginal and abandoned lands do represent varying levels of biodiversity. Management, harvest and trade-offs with biodiversity need to be assessed on a regional scale. Another important element is to what extent increased food demand may make it more attractive to use marginal lands for food production in the future and thus compete with bio-energy. Such dynamics can still not be investigated by current modelling tools.

The level of knowledge on this category is relatively poor and the lands in question in fact covers a wide variety of different settings, from semi-arid lands, degraded lands in various degrees, soils affected by salinity, etc. On the one hand, use of such lands for biomass may be very attractive because conflicts with food production are far less up to absent compared to arable lands. Furthermore, important co-benefits may be achieved such as regeneration of soils, improved water retention and (some) regained economic activity, which may prove even more important drivers than biomass production for energy alone. On the other hand, obtaining sustained biomass production, be it with low productivity, may bring high(er) costs

Overall (see also figure 4.4.1 of this report), this assessment tuned the broad range of estimates of global biomass resource potentials down to a range of minimally 200 EJ up to more than 400 EJ.

Another, perhaps remarkable, result of this assessment (but also confirmed by the recent IPCC 4th assessment report [IPCC, Chapter 11, 2007] is that current energy scenario's which include GHG mitigation strategies following IPCC guidelines, indicate that the demand for bio-energy until 2050 could in fact be limited compared to the potential biomass supplies, because various other options are more competitive in terms of specific mitigation costs. This may in particular be true for the use of biomass use for power generation because other alternatives (such as wind energy, fossils with Carbon Capture and Storage and nuclear energy) are more attractive. The estimated demand for primary biomass reported in this assessment (based on MARKAL and TIMER model results) amounts maximally 200 EJ. This is basically within the range of the indicated biomass resource potentials. In particular the residues and wastes can cover a very significant part of the demand to start with. Especially production of transport fuels (based on lignocellulosic biomass via 2nd generation technologies) is expected to play a dominating role on medium term. Biomass use for materials and feedstock adds to the demand, but is a minor factor in total demand based on most current model results, although this area has still received limited attention. It should be noted though, that the indications given by the IPCC, MARKAL and TIMER are based on relative cost effectiveness (e.g. costs per ton of CO2 emission avoided). Other drivers, such as energy security and rural development could result in sustained policy support in particular for biofuels. This may increase demand for biomass considerably. In addition, the total energy demand is uncertain and in the higher projections, biomass demand may rise well over the indicated 200 EJ.

It should be noted that the energy model results are in particular sensitive to assumptions on the expected performance of advanced conversion technologies (such as second generation biofuel production processes). It should also be noted that there is a wide range of energy models available which may yield different results than listed here. The main drivers for biomass demand though will not be different using other models.

The key studies that provided an important basis for the potential estimates mentioned are Hoogwijk et al., 2005 and Smeets et al., 2007. Given that those are the most recent studies available and that in particular the Hoogwijk study already incorporated various limitations with respect to nature areas, low productive areas, etc., these played an important role. The IPCC SRES scenario's used in the Hoogwijk analyses were used as a basis for this assessment as well, varying agricultural efficiency and using the base land cover simulations of the IMAGE model.

This assessment has provided several corrections of the available results to date, especially with respect to water availability, soil quality and protected areas (which were excluded from the potentials for biomass production). These are significant and led to corrections to earlier estimates of the resource potentials as argued above. Prime factors that influence that size of the potential are listed in table 5.2.1.

This assessment also showed different trade-offs from biomass/bio-energy production on biodiversity. From a perspective of global biodiversity targets, different spatial scales and both short and long term effects must be taken into account. On a local scale, biodiversity may benefit from growing biomass, when intensive agricultural practices are replaced by low-intensity biomass production systems (such as short-rotation forestry, mixed land-use systems). The large variation recorded in local effects deserves further attention, for defining favoured management practices. On a global scale however, agricultural lands may only become available when food production regions will shift, for instance through trade liberalization. Thus, the short-term global biodiversity effects are intimately related to global land-use dynamics and especially the different causes of land abandonment. On the long term, biomass production is expected to contribute to reduced greenhouse gas emissions and, therefore, reduced climate change effects on biodiversity. A first order estimate indicates that the balance between global biodiversity losses from increased land-use and reduced climate change effects from biomass production alone is not beneficial for biodiversity within 50 years. However, this conclusion is surrounded by considerable uncertainty, especially on climate change effects but also with respect to net biodiversity values of vegetation patterns and cropping systems. The latter may be strongly influenced by good practices and governance of land use. This element deserves further research.

5.2 Key uncertainties and weak spots or gaps in available knowledge

Uncertainties have been listed in chapter 4. Summarizing the findings of this study, the table below provides qualitative statements on status and impact of the various key uncertain issues and gaps of knowledge that have been identified.

Table 5.2.1 Overview of uncertainties and their impact on biomass resource potentials and recommended activities to reduce uncertainties.

Issue/effect	**Importance**	**Recommended activities to reduce uncertainties**
Supply potential of biomass		
Improvement agricultural management	***	Research to better understand how efficiency and livestock can be increased in a sustainable manner and for different settings. Insight in development pathways and feasible rates of improvement need to be integrated in modelling frameworks, Improved insights in pre-conditions for improvements can provide a basis for targeted policies.
Choice of crops	***	There are clear recommendations on the importance of lignocellulosic biomass production systems for different settings. Under certain conditions, sugar cane and palmoil could still be feasible options on longer term as well. Much more market experience with such production systems needed in different settings, including degraded and marginal lands, intercropping schemes (e.g. agroforestry) and management of grasslands. The latter is an important land-use category on which current understanding and data needs improvement.
Food demand	***	Increases in food demand beyond the base scenarios (e.g. up to 9 billion people in 2050) that were the focus in this study will strongly affect possibilities for bio-energy. Vice versa, limited population growth will mean the opposite.
Use of degraded land	***	Represents a significant share of total biomass resource supplies. Experiences with recultivation and knowledge on these lands (that represent a wide diversity of settings) is so far limited and distributed. More research and demonstration activities required to understand the economic and practical feasibility of using degraded/marginal land is needed. This land-use category also requires attention (e.g. via better databases) in modelling efforts.
Competition for water	***	Increased water demand for conventional agriculture, domestic and industrial use is a concern in various world regions, with agriculture being by far the most important sector in this respect. This assessment provided a first order insight in how techno-economic potentials may be constrained by water availability, which could be significant in some regions. Constraints in water supplies and sustainable management need ultimately to be studied on regional level (water basins
Use of agricultural /forestry by-products	**	Residues are an important resource category. The net availability for energy purposes can in the future in particular be affected negatively by competing applications (e.g. biomaterials and traditional biomass use). Their net availability can be positively affected by improved infrastructure and logistics. Key areas for research and sustainable management are maintaining sound organic matter levels in soils and nutrient balances. To some extent (especially for residues in tropical regions) more research and field experience to determine such levels is desired.
Protected area expansion	**	Increased ambition levels for nature reserves on global scale can have a significant impact on net land availability for biomass production. Land exclusion assumptions in the available studies however seem to overlap with the potential

		future land claims for nature and further modelling work and improved databases are desired. Furthermore, more insights are desired in how land use planning including new bio-energy crops can maximize biodiversity benefits. Evaluating biodiversity impacts on regional level is still a field under scientific development and more fundamental work is needed in this arena.
Water use efficiency	**	See above under competition for water). An important factor in the equation is improvement of water use efficiency in both conventional agriculture (that could be achieve through rationalization of management also driving up yields) and of biomass production itself. Improvement potentials are considerable compared to current average practice. This suggests that for various areas water management is prime design parameter for sustainable biomass production and land-use management. This area deserves considerable further research efforts, preferably linked to field experience.
Climate change	**	The impact of climate change on agricultural production and productivity of lands could be significant, but exact effects are also uncertain. Effective mitigation strategies, of which large scale bio-energy deployment could be a significant element, will limit the influence of this factor. At this stage, this is still the objective of the governments that have signed the Kyoto Protocol. Varying reported effects of climate change on natural systems and their biodiversity deserve further attention. Especially variation due to using different indicators and modelling concepts should be better explained. This will influence the balance between land-use dynamics and avoided climate change effects. Furthermore, although agriculture may face serious barriers due to climate change, this may also enhance the need for alternative adaptation measures to avoid soil losses and maintain vegetation covers. Biomass production (again especially via perennial systems) may than play a role as adaptation measure. Such strategies (under different climate change scenarios) are so for hardly studied and deserve further attention in future research efforts and scenario analyses.
Alternative protein chains	**	See above under food demand; Possible but very uncertain reversal of current diet trends, i.e. introduction of more novel plant protein products (as alternative for meat) could on the longer term strongly reduce land and water demand for food. Such options and the feasibility in terms of implementation are however insufficiently studied. Further work in this area is recommended.
Demand for biomaterials	*	Demand for biomass to produce biomaterials (both conventional as building material as new ones as bulk biochemicals and bioplastics) can be a significant factor, but is limited due to market size (and compared to demand for energy carriers). Furthermore, biomaterials will also end up as (organic) waste material later in their lifecycle, indirectly adding to increased availability of organic wastes. In many cases this 'cascaded use' of biomass increases the net mitigation effect of biomass use. For some biomaterial markets specific cropping and plantation systems may be required due to demands of the biomass composition. Biomaterials are so far poorly integrated as a factor in energy models and as mitigation option. This can be improved in further work to understand the interactions between different flows and markets better (also in macro-economic terms).
GHG balances of biomass chains	*	The net GHG performance of biomass production systems is not identified as a limiting factor for the potential, provided perennial cropping systems are considered. Also, striving for biomass production that is similar or better than previous land use (e.g. grasslands that remain grasslands or trees that replace annual crops) generally improves the overall carbon balance. This can also be true for replanting of degraded lands. The key factor in the net carbon balance is leakage. Avoiding leakage is directly related to increased efficiency in agriculture and livestock and net carbon impacts of biomass production should include this dimension. Such dynamics should ideally also be incorporated in future modelling excercises.
Demand potential of biomass		
Bio-energy demand versus supply	**	The data on potential biomass demand in future energy scenarios reported in this study hint that biomass demand may in fact be lower than the biomass supplies that could be generated in baseline scenario's used (as DV-2). The key demand factor is likely to be the use of biomass for transport fuels due to the very few

		alternatives available for oil and reducing CO2 emissions in the transport sector. Nevertheless, long term energy demand projections are also characterized by considerable variability (especially caused by GDP and population growth and the rate of deployment of energy efficiency measures at large). Demand for for example transport fuels could therefore also be significantly higher than projected in this report and this could be further enhanced when policies target increased energy security and rural development as other priorities that are likely to favor biomass and biofuels. It is recommended to incorporate (dynamic) biomass supply projections and a more diverse portfolio of conversion options (e.g. including hydrogen production from biomass and combined with CCS) in current models to obtain more coherent analyses and scenario's.
Cost of biomass supply	**	The costs of biomass supplies are influenced by the degree of land-use competition, availability of (different) land (classes) and optimisation (learning) in cropping and supply systems. The latter is still relatively poorly studied and incorporated in scenario's and (energy and economic) models, which can be improved. Nevertheless, the variability of biomass production costs seems far less than that of oil or natural gas, so uncertainties in this respect are relatively limited.
Learning in energy conversion	**	See remarks on energy models and costs of biomass supply; better insights in development potentials of key technologies (2nd generation systems) and biomass supplies will improve the quality of scenario results with respect to the relative role of biomass for energy (and materials).
Market mechanism food-feed-fuel	**	To date, limited modelling efforts are available to fully interlink macro-economic/market models with biomass potential studies, especially when lignocellulosic biomass is concerned. To date, price dynamics and, longer term, responses of agriculture (in terms of increased land use and/or increased efficiency) are also addressed to a limited extent. Although the long term impacts on actual physical biomass resource potentials may be limited, understanding the economic responses to increased demand for food and bio-energy and how these affect the relative competitiveness of bio-energy compared to other energy supply options is extremely important for defining balanced policy strategies. Linked to this, socio-economic implications (such as impacts on rural income, rural employment) should be further understood.

Importance of the issues on the range of estimated biomass potentials: ***- large, ** - medium, * – small

5.3 Policy advice and key pre-conditions for sustainable development of biomass resources.

As summarized, the size of the biomass resource potentials and subsequent degree of utilisation depend on numerous factors. Part of those factors are (largely) beyond policy control. Examples are population growth and food demand. Factors that can be more strongly influenced by policy are development and commercialization of key technologies (e.g. conversion technology for producing fuels from lignocellulosic biomass and perennial cropping systems), e.g. by means of targeted RD&D strategies. Other areas are:

- Sustainability criteria, as currently defined by various governments and market parties..
- Regimes for trade of biomass and biofuels and adoption of sustainability criteria (typically to be addressed in the international arena, for example via the WTO).
- Infrastructure; investments in infrastructure (agriculture, transport and conversion) is still an important factor in further deployment of bio-energy.
- Modernization of agriculture; in particular in Europe, the Common Agricultural Policy and related subsidy instruments allow for targeted developments of both conventional agriculture and bio-energy. Such developments are however crucial for many developing countries and are a matter for national governments, international collaboration and various UN bodies (such as FAO).
- Nature conservation; policies and targets for biodiversity protection do determine to what extent nature reserves are protected and expanded and set standards for management of other lands.
- Regeneration of degraded lands (and required preconditions), is generally not attractive for market parties and requires government policies to be realized.

Although this assessment was not specifically targeting formulation or further design of sustainability criteria for biomass production, the results provide leads for further steps for doing so. In the criteria framework as defined by the Netherlands by the so-called ‘Cramer Committee’ [Cramer et al., 2007], it is highlighted that a number of important criteria require further research and design of indicators and verification procedures. This is in particular the case for to the so-called ‘macro-themes’ (land-use change, biodiversity, macro-economic impacts) and some of the more complex environmental issues (such as water use and soil quality).

This study has confirmed that in principle biomass resource potentials (for energy) could be very large on a global scale (up to one third of global energy demand following more average projections for energy demand as well as biomass resource potentials). This globally justifies policies that target large scale deployment of for example biofuels. However, only a smaller part of the larger potential estimates will be almost certainly available (namely the biomass residues and organic wastes). The larger part of the potential has to be developed via cultivation and has to meet a wide variety of sustainability criteria to avoid conflicts with respect to water use, land-use competition, protected areas, biodiversity, soil quality and socio-economic issues. Based on the findings in this assessment, for large parts of the resource potentials the indications are that such conflicts can indeed be avoided or may in parts even result in co-benefits. The latter could be true for using degraded lands (impacts on soils and biodiversity), combined strategies for modernization of agriculture and introduction of biomass as a diversification strategy (e.g. agroforestry systems).

Both in size and in terms of meeting this wide array of criteria, annual food crops are not suited as a prime feedstock for bio-energy. Perennial cropping systems, however, offer very different perspectives. These cannot only be grown on (surplus) agricultural and pasture lands, but also on more marginal and degraded lands, be it with lower productivity. Such cropping system represent a very diverse set of possible production systems, from low intensity forestry like operations and managed existing grasslands, up to highly productive plantations with short rotation coppice systems or energy grasses like Miscanthus. At this stage there is still limited (commercial) experience with such systems for energy production, especially considering the more marginal and degraded lands and much more research and demonstration work is needed to develop feasible and sustainable systems suited for very different settings around the globe. This is a prime priority for agricultural policy.

Most challenging in harnessing biomass production potentials in a sustainable way is probably the design of governance and implementation strategies. Such strategies should allow for gradual introduction of biomass cropping systems into rural regions and simultaneously increasing agricultural and livestock productivity. As confirmed by this study, those productivity increases are an essential component to avoid conflicting claims on land and to strong competition (e.g. via increased prices for food). This assessment as a whole points out that policies targeting development of bioenergy use and biomass production should incorporate a variety of targets and boundaries. Including a strict GHG criterion (e.g. 90% compared to reference fossil energy use) will lead to different choices for crops and land management compared to a situation where no criterion is formulated. This is also true for sustainable management of water resources, biodiversity, as well as rural development. Such a holistic approach could avoid conflicts and ultimately maximize synergies. Clearly, the balance of objectives will be different from setting to setting (compare rural Africa with the EU for example) and trade-offs have to be made. It is argued here that such trade-offs should be explicit, balanced and incorporate clear boundaries that should be respected and used as a starting point for developing biomass production in a give region. Governance and deployment of incentives (such as subsidies or obligations) could than also be designed to achieve just that. This is a fairly sharp contrast to some of the current biofuel policies implemented in the EU and the US.

5.4 Research needs

This assessment study has identified a long, but also well specified list of research topics that need to be addressed to provide more precise answers and tools. Those topics include:

- Integration of modelling efforts of the various arenas included in this assessment, in particular macro-economic/market models that are interlinked with integrated assessment tools and bottom-up analyses of agricultural, livestock and biomass production systems.
- Such improved modelling tools should also improve our understanding of the impact of various policy incentives (such as subsidies, trade policies, climate policies) on agriculture, livestock, land-use and, ultimately, biomass resource availability.
- Strengthen the science base for evaluating impacts on biodiversity of land use change and changes in vegetation patterns, including improved indicator systems for quantifying biodiversity.
- The interlinkages between climate change, agricultural productivity, land-use change, biodiversity and subsequent consequences for biomass resource potentials should be better understood and modelled. One element is to understand the possibilities of biomass production in the context of adaptation measures for climate change and maintaining vegetation in climate change affected areas.
- Improved understanding of marginal and degraded lands and potential biomass production systems with their respective performance and impacts.
- Improved databases are required for soil quality and land-use functions & categories; such basic data are an important prerequisite for more reliable model outcomes.
- More detailed, preferably on the level of water basins, analysis of the impacts of changed land use and vegetation patterns on water use. Such analyses should also include improved understanding of ways to limit water use via improved (crop) management or vegetation strategies.
- Improve the understanding of how agricultural management and efficiency can be improved and via what strategies. This should be studies for a wide variety of settings, covering subsistence farming systems in Africa up to the more intensive farming systems in e.g. Eastern Europe.
- Concrete case studies on the full range of impacts (ecological and socio-economic) and performance (production levels, costs) of biomass production (and supply) systems in concrete settings, in particular covering more difficult circumstances such as by using degraded lands.

Many more specific and detailed recommendations can be derived from this assessment. It is overall recommended to address those research gaps and needs in a comprehensive manner, because the long list of uncertainties and scientific questions illustrate that the results of this assessment still come with uncertainties. Current modelling tools (such as IMAGE, Quickscan, GLOBIO, WATERGAP, GTAP, AgLink and some energy models) could be deployed in a more integral framework, but partially also require new model development. Some key issues listed are not part of current key modelling tools, thereby producing incomplete answers to questions posed. In addition, in various areas dedicated methodology development and more basic system analysis research is needed. Such work can feed into the development of an improved modelling framework and will enable the research community to provide decent answers to key question posed by policy and the market.

Having such analytical capabilities at hand is of crucial importance for designing targeted policies. This is true for designing strategies, identifying early opportunities and especially for tackling the questions posed by the introduction of sustainability criteria for biomass and bioenergy. Better understanding of the dynamics in land-use, agriculture, (as outlined above) will also provide better insights in how implementation strategies may be designed and, last but not least, give improved insight in the impacts of deploying various incentives (such as subsidies).

References

Biomass potential studies for review

Fischer, G., S. Prieler and H. van Velthuizen, 2005, Biomass potentials of miscanthus, willow and poplar: results and policy implications for Eastern Europe, Northern and Central Asia, Biomass and Bioenergy, 28(2), 119-132.

Hoogwijk, M., A. Faaij, B. Eickhout, B. de Vries and W.C. Turkenburg, 2005, Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios, Biomass & Bioenergy, 29(4), 225-257.

Hoogwijk, M., A. Faaij, B. de Vries and W.C. Turkenburg, 2004, Global potential of biomass for energy from energy crops under four GHG emission scenarios Part B: the economic potential, In: M. Hoogwijk, On the global and regional potential of renewable energy sources, PhD Thesis, Utrecht University, 2004.

Obersteiner, M., G. Alexandrov, P.C. Benítez, I. McCallum, F. Kraxner, K. Riahi, D. Rokityanskiy and Y. Yamagate, 2006, Global supply of biomass for energy and carbon sequestration from afforestation/reforestation activities, Mitigation and Adaptation Strategies for Global Change 11(5-6), 1003-1021.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes and D.C. Erbach, 2005, Biomass as feedstock for a bioenergy and bioproduts industry: The technical feasibility of a billion-ton annual supply, Oakridge National Laboratory ORNL/TM-2005/66

Rokityanski, D., P. Benitez, F. Kraxner, I. McCallum, M. Obersteiner, E. Rametsteiner and Y. Yamagata, in press, Geographically explicit global modeling of land-use change, carbon sequestration and biomass supply, Technological Forecasting and Social Change, In Press, available online 4 October 2006.

Smeets, E.M.W., A.P.C. Faaij, I.M. Lewandowski and W.C. Turkenburg, 2007, A bottom-up assessment and review of global bio-energy potentials to 2050, Progress in Energy and Combustion Science, 33(1), 56-106.

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

Other recent studies and reviews

Berndes, G., 2002, Bioenergy and water—the implications of large-scale bioenergy production for water use and supply, Global Environmental Change, 12(4), 253-271

Berndes, G., M. Hoogwijk and R. van den Broek, 2003, The contribution of biomass in the future global energy supply: a review of 17 studies, Biomass and Bioenergy, 25(1), 1-28.

Dam, J. van, A. Faaij and I. M. Lewandowski, 2005, Biomass production potentials in Central and Eastern Europe under different scenario's. Final report of WP 3 of the VIEWLS project, report NWS-E-2005-87, commissioned by DG-TREN, Copernicus Institute, Utrecht University, Utrecht, The Netherlands.

Ericsson, K. and L.J. Nilsson, Assessment of the potential biomass supply in Europe using a resource-focused approach, 2006, Biomass and Bioenergy 30(1), 1-15

Gielen, D.J., J. Fujino, S. Hashimoto, and Y. Moriguchi, 2002, Biomass strategies for climate policies, Climate Policy 2, 319-333.

Hoogwijk, M., A. Faaij, R. van den Broek, G. Berndes, D. Gielen and W. Turkenburg, 2003, Exploration of the ranges of the global potential of biomass for energy. Biomass and Bioenergy, 25(2), 119-133.

Rogner H. (Convening Lead Author), A. Faaij (Lead Author), et al., 2000, Energy Resources. Chapter 5 of the World Energy Assessment of the United Nations, UNDP, UNDESA/WEC, UNDP, New York.

Schneider, U.A. and B.A. McCarl, 2003, Economic potential of biomass based fuels for greenhouse gas emission mitigation, Environmental and Resource Economics 24, 291-312.

Smeets, E.M.W. and A.P.C. Faaij, in press, Bioenergy potentials from forestry in 2050 - An assessment of the drivers that determine the potentials, Climatic Change (in press), available online 30 November 2006.

Yamamoto, H., J. Fujino and K. Yamaji, 2001. Evaluation of bioenergy potential with a multi-regional global-land-use-and-energy model, Biomass and Bioenergy 21, 185-203, 2001.

USCCSP, 2006, Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Report by the U.S. Climate Change Science Program and approved by the Climate Change Science Program Product Development Advisory Committee. Clarke, L., J. Edmonds, J. Jacoby, H. Pitcher, J. Reilly, R. Richels (Eds), 2006.

WWI, 2006, Biofuels for transportation – Global potential and implications for sustainable agriculture and energy in the 21st century. Worldwatch Institute, Washington D.C.

Additional references mentioned in specific chapters

(note: see separate Supporting Document for all references)

1. Introduction

WEA, 2000 …………….
WEA, 2004 ………….
IEA 2006b
Faaij et al 2005

2.3 Water

Molden, D., K. Frenken, Ch. De Fraiture, R. Barker, B. Mati, M. Svendsen, C.Sadoff, C.M. Finlayson, 2007, Trends in water and agricultural development, In: David Molden (ed.) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, 57-89.

Alcamo, J., P. Döll, T. Henrichs, F. Kaspar, B. Lehner, T. Rösch and S. Siebert. 2003. Development and testing of the WaterGAP 2 global model of water use and availability. Hydrological Sciences Journal, 48(3): 317-338.

Shiklomanov, I.A., 2000. Appraisal and assessment of world water resources, Water International 25, 11-32.

2.4 Food

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

Evans, L.T., 1998, Feeding the ten billion: Plants and population growth, ISBN 0-521-64081-4, Cambridge University Press, Cambridge, UK.

Aiking, H., J. De Boer and J.M. Vereijken (Eds.), 2006a, Sustainable protein production and consumption: Pigs or peas?, Environment & Policy Vol. 45, ISBN 1-4020-4062-8, Springer, Dordrecht, The Netherlands.

Bruinsma, J., 2002, World agriculture: Towards 2015/2030, An FAO perspective, ISBN 9251048355, FAO, Rome, Italy.

Von Braun, J., M. Rosegrant, R. Pandya-Lorch, M.J. Cohen, S.A. Cline, M.A. Brown and M.S. Bos, 2005, New risks and opportunities for food security: Scenario analyses for 2015 and 2050, 2020 Discussion paper 39, IFPRI, Washington DC.

Dixon, J., A. Gulliver and D. Gibbon, 2001, Farming systems and poverty; Improving farmers' livelihoods in a changing world, FAO and World Bank, Rome, Italy and Washington DC, USA.

Grigg, D., 1995, The pattern of world protein consumption, Geoforum 26(1), 1-17.

Millstone, E. and T. Lang, 2003, The atlas of food: Who eats what, where and why, ISBN 1-85383-965-5, Earthscan Publications Ltd, London, UK.

Smil, V., 2002b, Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins, Enzyme and Microbial Technology 30, 305-311.

Pimentel, D. and M. Pimentel, 2003, Sustainability of meat-based and plant-based diets and the environment, American Journal of Clinical Nutrition 78, 660S-663S.

Smil, V., 2000, Feeding the world: A challenge for the twenty-first century, ISBN 0-262-19432-5, MIT Press, Cambridge (Mass.), USA.

Seidl, A., 2000, Economic issues and the diet and the distribution of environmental impact, Ecological Economics 34, 5-8.

White, T., 2000, Diet and the distribution of environmental impact, Ecological Economics 34, 145-153.

3.6 Greenhouse gas balances

Larson, E. D. (2007). "A review of LCA studies on liquid biofuel systems for the transport sector." Energy for sustainable development **X**(2): 109-126.

Quirin, M., Gärtner, S.O., Phent, M., Reinhardt, G.A. (2004). CO2 mitigation through Biofuels in the transport sector - status and perspectives. Heidelberg, IFEU.

WWI (2006). Biofuels for transportation - Global potential and implications for sustainable agriculture and energy in the 21th century. Washington, D.C., Worldwatch Institute.

JRC (2007). Well-to-wheels analysis of future automotive fuels and powertrains in the European context - version 2c, March 2007, Joint Research Centre.

Wicke, B., V. Dornburg, et al. (2007). A Greenhouse Gas Balance of Electricity Production from Co-firing Palm Oil Products from Malaysia. Utrecht, The Netherlands, Science, Technology and Society, Copernicus Institute, Utrecht University.

4.2 Issues not covered

Patel, M.K., Crank, M., Dornburg, V., Hermann, B.G., Roes, L., Hüsing, B., Overbeek, L. van, Terragni, F., Recchia, E. (2006). Medium and longterm opportunities and risks of the biotechnological production of bulk chemicals from renewable resources. E.C.G.P.D. Research). Utrecht, the Netherlands.

Dornburg, V. and A.P.C. Faaij (2005). "Cost and CO2-emissions reduction of biomass cascading: methodological aspects and case study of SRF poplar." Climatic Change(71): 373-408.

4.4 What we know and don't know

WEA, 2000 …………….

OECD-FAO Agricultural Outlook 2007-2016.

5.1 Main conclusions

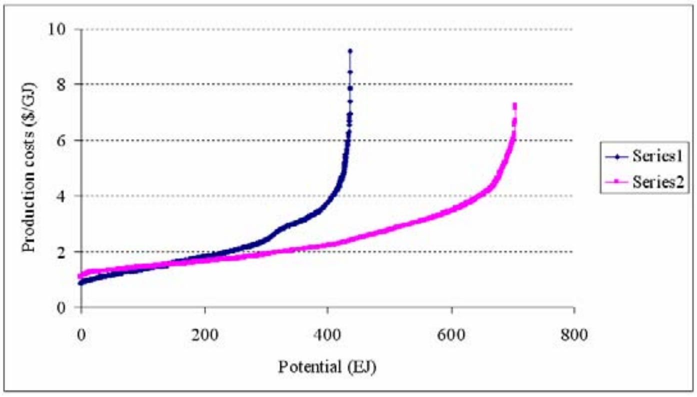
IPCC 4th Assessment Report

Appendix 1 Analyses of several demand-side energy scenarios in Timer and Markal

A1.1 Timer-based demand-side energy scenarios

A1.1.1 General

The two curves below depict supply curves of woody biofuels in 2030 and 2050. The increase on the low site of the curve is determined by increasing production costs in low income countries. The decrease on the high side is due to yield increases. Expansion of the curve is both due to yield increases and an increase in abandoned agricultural land.

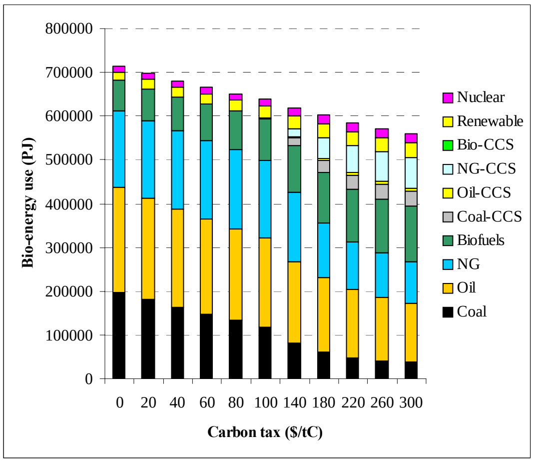


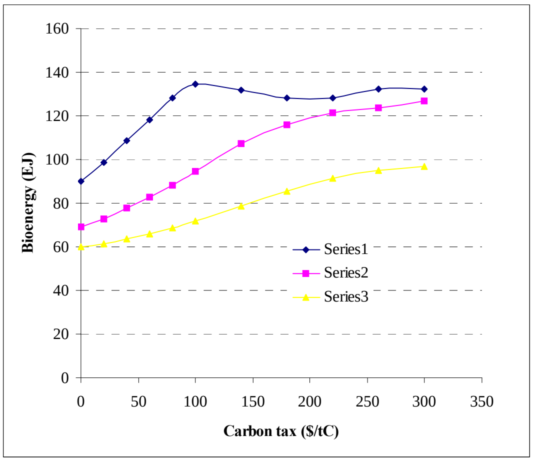
Costs indicated here only include production of raw material. Transport costs and conversion to usable material, e.g. for power add about 2$/GJ for the whole curve for use as biofuel for power. The conversion and transport adds about 10$/GJ for conversion to liquid biofuels.

A1.1.2 Overall system

Below the results are shown of a model experiment in which the carbon tax is increased from 0 to 300 US$/tC. Biofuels here include both traditional and modern biofuels. As a result of the carbon tax, fossil fuel use is significantly reduced – and partly replaced by nuclear, renewables, biofuels and CCS.

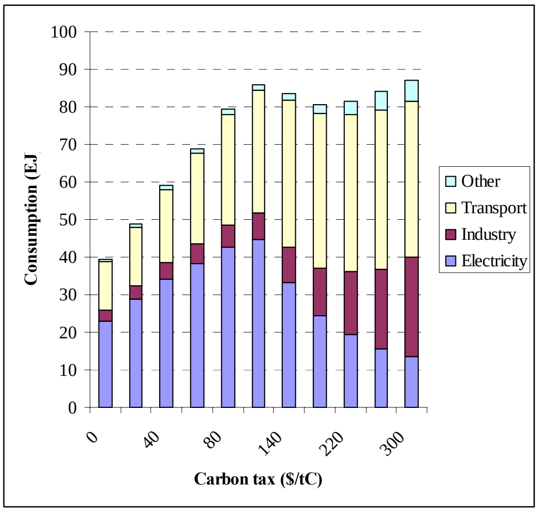
Graph on the right shows biofuel use (after conversion to liquid fuel or electric power input). The lines are 2020, 2030 and 2050. In the 2050 curve, supply more or less stabilizes at 130 EJ.





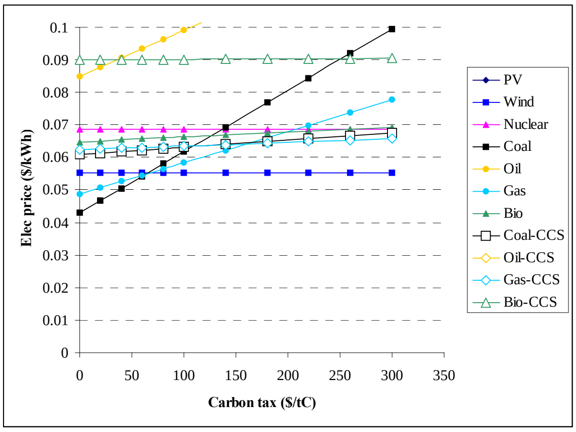
The next graph shows the use of modern biofuels by sector in the year 2050. At low carbon prices, most biofuels are used in electricity. Biofuel use here increases with increasing prices.

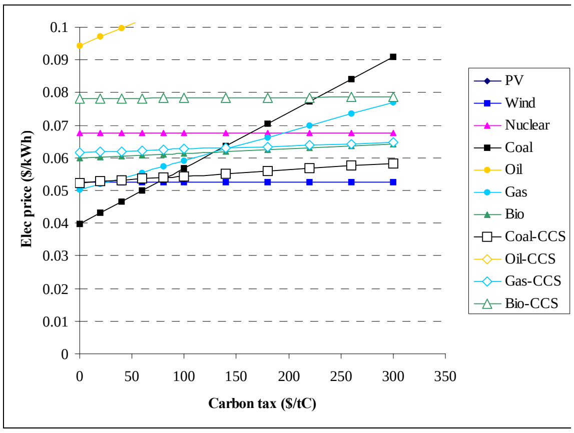
However, beyond 100$/tC biofuel use drops in this sector – and a rapid expansion takes place both in transport and industry/non-energy use.



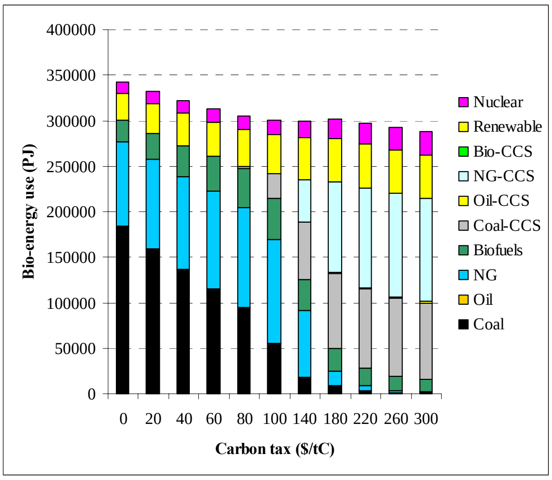
A1.1.3 Electric power

In electric power, at low carbon taxes coal fired plants are the preferred technology both in 2020 and 2050. Natural gas represent a second choice (data is shown for Western Europe). With increasing taxes, wind becomes the cheapest alternative – but its costs become more expensive with increasing penetration in the system (not shown). Bio-energy is among several other options, including coal CCS, natural gas-CCS, at low carbon prices natural gas, nuclear. To be fully competitive, bio-energy should have costs in the order <3 US$/GJ at carbon prices below 100 US$/tC, and <4US$/GJ at carbon prices beyond this point. In 2050, the situation is somewhat changed due to the decline of coal-CCS. As a result, bio-energy costs now need to be below 2-3 US$/tC over the whole range to remain competitive. As demand in other sectors for biofuels increases, biofuel prices however are much more likely to increase.



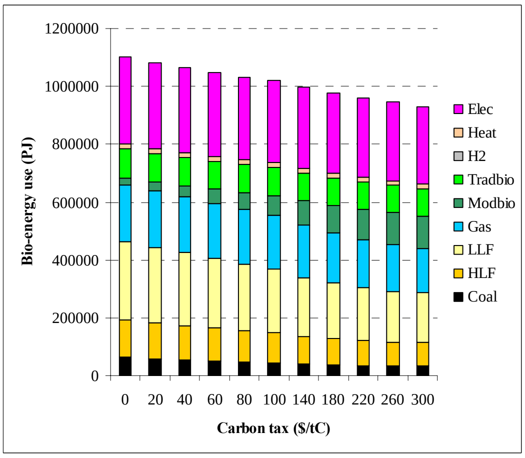


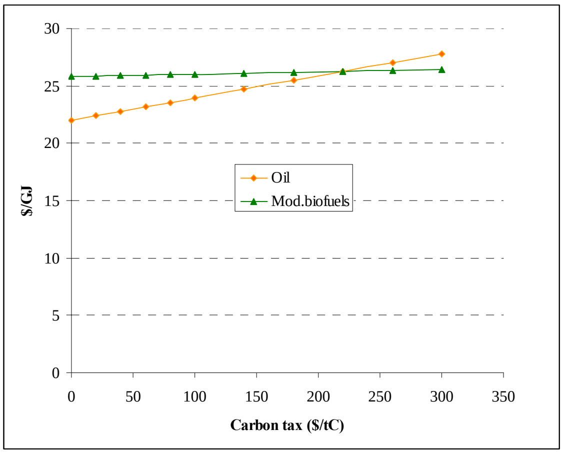
The result is shown in Figure where bio-energy demand increases at low carbon prices – but declines at higher prices, driven out by coal-CCS, natural gas-CCS and other renewable.



A1.1.4 End use

In end-use biofuel increases with increasing carbon prices. The most important sector is transport. Here, biofuel increases in competition with oil. As indicated, somewhere in the range of 200-250 US$/tC the situation changes from oil as the cheaper alternative to a situation in which biofuels are the cheaper alternative (crude oil price around 40$/bbl). Thus, again the range of biofuel prices that give a reasonable change of competition for use in transport depend on the carbon price and the oil price. At 40$/bbl, primary biofuel costs in the order of 4-5$/GJ primary costs could be competitive at a carbon price of 150 $/tC and higher.





A1.2 Markal-based demand-side energy scenarios

A1.2.1 General assumptions

Five scenarios are considered, with the assumptions as presented in table A.1.1. Table A.1.2 presents the assumptions concerning the oil prices. Table A.1.3 presents the assumptions regarding the CO_2 reduction costs in the CM scenarios. Finally, table A.1.4 presents the biomass potentials for 2010-2050, as applied in the TDT scenarios.

Table A1.1: Assumptions scenarios

	Scenario	CO_2 price €/tonne	Biomass potential	Oil/gas price	Comment
1	CM BL (Cascade Mints Baseline)	±10	High	Low	

2	CM CV 100 (Cascade Mints Carbon Value 100 €/tonne)	100	High	Low	
3	CM TP CV	100	High	Low	Assumptions the same as CM CV 100, but with 50% more rapid learning for all the selected and renewable technologies (nuclear, renewables, hydrogen, also gasifiers both coal and biomass-based)
4	TDT DD (Transitie Denk Tank Duurzaam Denktank)	88 as result of 30% CO_2 reduction target	Low (E15+N+CH +ICE)	High(er)	
5	TDT BS (Transitie Denk Tank Biomassa Schaarste)	88 as result of 30% CO_2 reduction target	Lower	High(er)	

Table A1.2: Assumptions oil prices (€$_{2000}$/GJ)

Scenario	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
CM	3.77	4.40	4.20	4.80	5.80	6.02	6.25	6.12	5.99	5.94	5.88	5.82
TDT	3.97	4.34	5.97	7.82	9.79	12.51	15.54	15.22	14.90	14.76	14.62	14.47

Table A1.3: Assumptions CO_2 reduction costs (€/tonne CO_2) in CM scenarios

Scenario	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
CM BL	0	0	0	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13
CMCV100	0	0	10	50	100	100	100	100	100	100	100	100

Table A.1.4 Biomass potentials for 2010-2050 (PJ), as applied in the TDT scenarios

Constraint	2010		2020		2030		2040		2050	
	TDT DD	TDT BS	TDT DD	TDT BS	TDT DD	TDT BS	TDT DD	TDT BS	TDT DD	TDT BS
Agriculture	1260	1260	2642	2642	4124	4124	5000	5000	5000	5000
Forestry	3016	1760	3286	1612	3717	1624	3717	1624	3717	1624
Waste	3965	3965	3986	3986	4028	4028	4100	4100	4200	4200
Total	8241	6985	9914	8240	11869	9776	12817	10724	12917	10824

In the following two paragraphs some of the results of the scenario studies for the year 2050 are presented. All the considered scenarios include carbon capture and storage technologies. Regarding the presented results the following comments should be made:

- Biomass residues contain waste and landfill gas (LFG) as input;
- Waste used for electricity generation consists of not only organic waste, but also plastics, etc.;
- Waste in table A.1.4 consists of only organic waste (including LFG);
- Energy crops: when used for electricity generation is mainly wood chips from forestry, in other cases (primary energy demand, biofuels) it also includes agricultural crops.

A1.2.2 CM scenarios

In the CM scenarios the cost of CO_2 emission reduction is the only input parameter that has been changed. However, this change has an effect on the technology costs due to the application of another technology mix, imposed by the CO_2 tax. The latter will result in another capacity building and therefore to different costs, according to the learning curves.

As presented in figure A.1.1, a higher CO_2 tax (100 €/tonne) in the CM CV 100 scenario, compared to the CM BL scenario (10 €/tonne) results in a decrease of 60% in the share of oil demand as primary energy, and 20% in the share of coal, while the share of nuclear energy increases for 18%. Also the share of biomass (energy crops) has increased for 68%, while wind energy achieves a share of 7% in primary energy, compared to 0.2% in the CM BL scenario. The contributions of gas, hydro, solar energy, and biomass residues remain almost unchanged. A more rapid learning in CM TP CV compared to CM CV 100 is mainly advantageous for solar at the cost of fossil fuels/hydro. Table 5 presents the Primary energy demand in the CM scenarios.

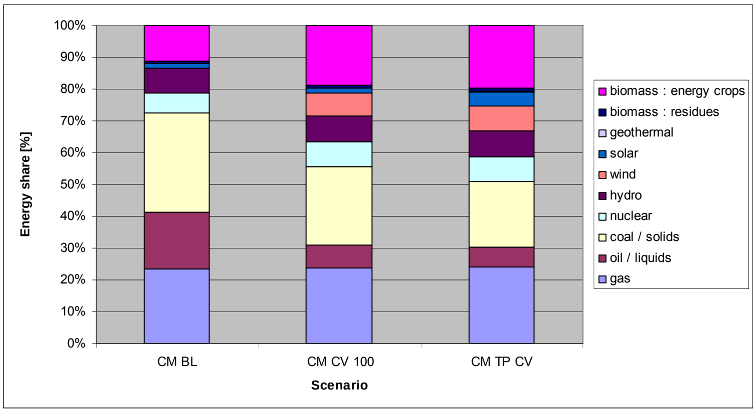


Figure A.1.1 Primary energy share (CM scenarios, 2050)

Table A.1.5 Gross inland primary energy consumption (PJ) in the CM scenarios (2050)

	CM BL	CM CV 100	CM TP CV
Gas	18328	18278	17474
Oil / liquids	13782	5580	4515
Coal / solids	24345	18867	14949
Nuclear	5040	5855	5853
Hydro	5890	6359	5908
Wind	189	5529	5529
Solar	1064	1115	3251
Geothermal	114	114	114
Biomass : residues	515	733	733
Biomass : energy crops	8676	14323	14362
Total	77943	76753	72688

In the power sector, as presented in figure 2, a higher CO_2 tax results in a lower share of power produced from fossil fuels, and a higher share of power generated by wind energy and biomass (energy crops) in CM CV 100. The marginal cost of electricity mix increases for 40% from 4.08 to 5.78 €ct/kWh (figure 3). A more rapid learning in CM TP CV compared to CM CV 100 is advantageous for solar at the cost of coal/gas/biomass-based CCS (see also table 6), and the marginal cost of electricity mix will slightly decrease. The contribution of different fuel/technoloy combinations to electricity generation is presented in table A6.

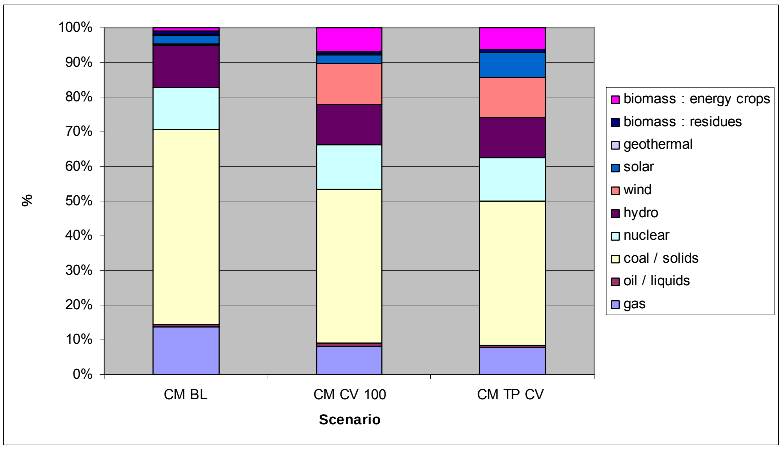


Figure A.1.2 Share of net electricity generation (CM scenarios, 2050)

Table A.1.6 Electricity production (TWh) in the CM scenarios (2050)

	CM BL	CM CV 100	CM TP CV
Coal	490.2	0.0	0.0
Coal CCS	1665.9	1897.9	1796.3
Oil	31.8	31.8	31.8
Gas	525.6	264.8	264.4
Gas CCS	0.0	86.6	71.9
Nuclear	466.7	542.2	541.9
Hydro	470.3	483.6	490.4
Wind	17.5	512.0	512.0
Solar	98.6	103.2	301.0
Geothermal	10.5	10.5	10.5
Biomass energy crops	0.4	0.0	0.0
Biomass energy crops CCS	0.0	122.0	103.3
Biomass residues (waste + LFG)	68.7	110.7	110.7
Biomass residues CCS	0.0	91.2	91.2
Total	3846.1	4256.4	4325.5

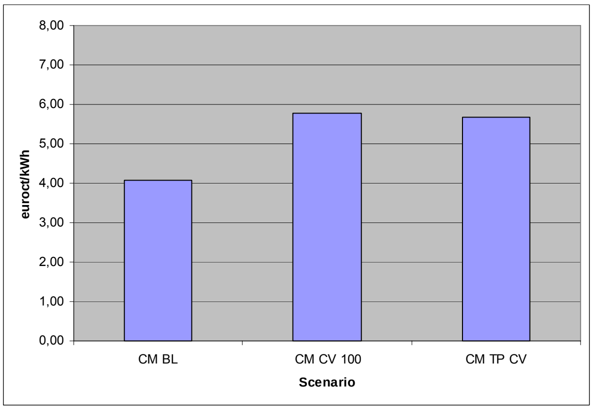
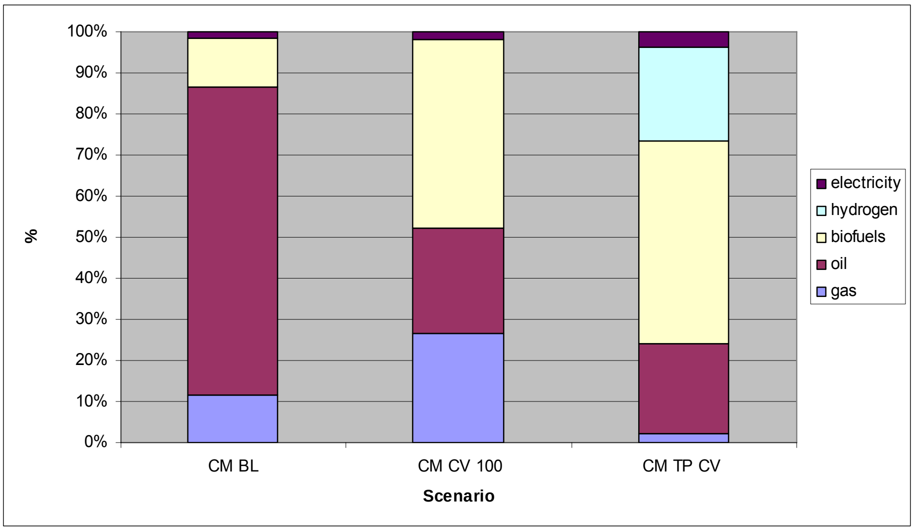


Figure A.1.3 Marginal cost of electricity mix (CM scenarios, 2050)

Because there is a high biomass potential, the supply of biomass is not a limitation in the CM scenarios. However, a higher CO_2 tax results in a higher demand for biomass at a higher price. Biomass origin and marginal costs for some biomass flows in the CM scenarios are presented in table 7. From table 7 it can be seen, that none of the scenarios use biomass from the agricultural sector. The reported marginal costs for sugar beet should therefore be related to the food sector. From figure 4 it can be seen, that the share of biofuels increases from 12% in the CM BL scenario to 46% in the CM CV 100 scenario. The share of oil decreases for 65%, while the share of gas in the transport sector is more than doubled. Electricity has a very limited share, and hydrogen has no share in the transport sector. A more rapid learning in CM TP CV compared to CM CV 100 results in the introduction of hydrogen with a share of 23% to this sector, a doubling of the electricity share, slightly increase of the biofuels share, a dramatic decrease of gas, and a slightly decrease of oil share to this sector.

Table A.1.7: Biomass origin (PJ) and marginal costs for some biomass flows (€/GJ) in the CM scenarios (2050)

	CM BL (PJ)	CM CV 100 (PJ)	CM TP CV (PJ)	CM BL (€/GJ)	CM CV 100 (€/GJ)	CM TP CV (€/PJ)
Agriculture						
Sugar beet	0	0	0	24.94	26.29	26.20
Algae	0	0	0			
Total	0	0	0			
Forestry						
Wood chips				2.26	8.70	8.72
Domestic	1295	4864	4864			
Imported	868	3137	3137			
Total	2163	8001	8001			
Waste						
Straw	2000	1904	1944	2	7.38	7.41
Bark	57	274	274			
LFG	389	884	884	7.39	10.75	10.77
Kitchen waste	125	410	410			
Paper waste	332	47	47			
Total	2903	3519	3559			



FigureA.1. 4 Share of final energy demand in transport sector (CM scenarios, 2050)

A1.2.3 TDT scenarios

In the TDT scenarios the biomass potential is the only input parameter that has been changed. The supply of biomass is limited to EU15+N+CH+ICE in the TDT DD scenario, and even more limited in the TDT BS scenario[6]. The biomass costs are the same in both scenarios. Marginal costs for some biomass flows are presented in table A.1.8.

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[6] For forestry two “bounds” are included, one on domestic forest and afforestation, and one on import (30 to 50 Mtoe in 2010-2030 and further). Wood chipping from the latter one has been put to zero for the TDT BS case (not the import as such).

Table A.1.8 Marginal costs for some biomass flows (€/GJ) in the TDT scenarios (2050)

	TDT DD	TDT BS
Wood chips	17.57	21.52
Straw	16.14	20.08
LFG	15.28	15.85
Paper wastes	0	0
Sugar beet	27.74	28.35
Starch	8.44	10.63
Sorghum	10.10	13.06

Due to higher oil prices in the TDT scenarios (table A.1.2) the share of fossil fuels in the primary energy is much lower compared to the CM scenarios, while the share of nuclear energy is almost doubled (figures A.1.5 and A.1.1). Compared to the CM CV 100 scenario, a higher share for the wind energy and a much higher share for the solar energy are achieved in the TDT scenarios. However, the share of biomass in the TDT scenarios (12%) is lower than in the CM CV 100 scenario (19%), due to the relatively limited supply potential of biomass (mainly in the forestry) in the former cases. Table A.1.9 presents the primary energy demand in the TDT scenarios.

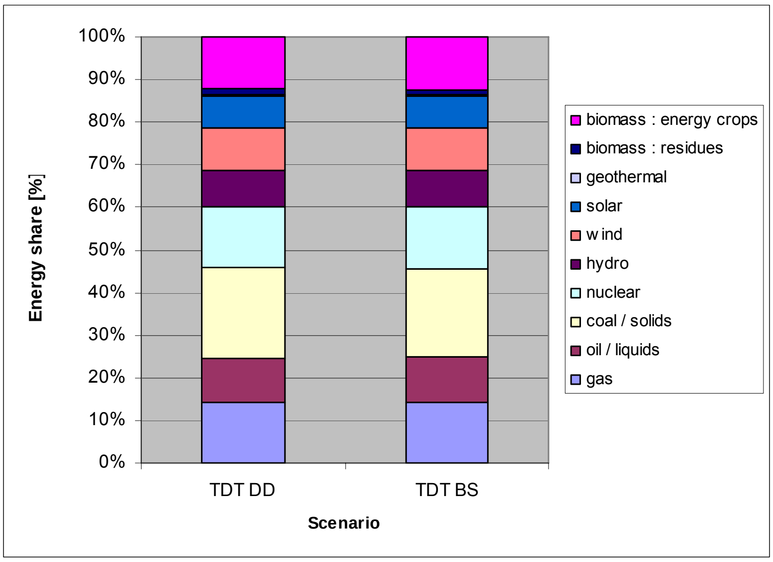

Figure A.1.5: Primary energy share (TDT scenarios, 2050)

With respect to power production the share of fossil fuels is lower than 40% (figure A.1.6), compared to 50-70% in the CM scenarios (figure A.1.2). The share of nuclear power, wind and solar power are much higher than in the CM scenarios. The contribution of biomass (energy crops) in the TDT DD scenario is higher than in the TDT BS scenario, and in both cases lower than in the CM CV 100 scenario. The marginal cost of electricity mix is 7.6 to 7.7 €ct/kWh (figure A.1.7). The contribution of different fuel/technology combinations to electricity generation is presented in table A.1.10.

Table A.1.9: Gross inland primary energy consumption (PJ) in the TDT scenarios (2050)

	TDT DD	TDT BS
Gas	11011	10945
Oil / liquids	7814	7958
Coal / solids	16178	15846
Nuclear	11016	11016
Hydro	6582	6545

Wind	7631	7635
Solar	5810	5810
Geothermal	114	114
Biomass : residues	1007	1011
Biomass : energy crops	9368	9388
Total	76531	76268

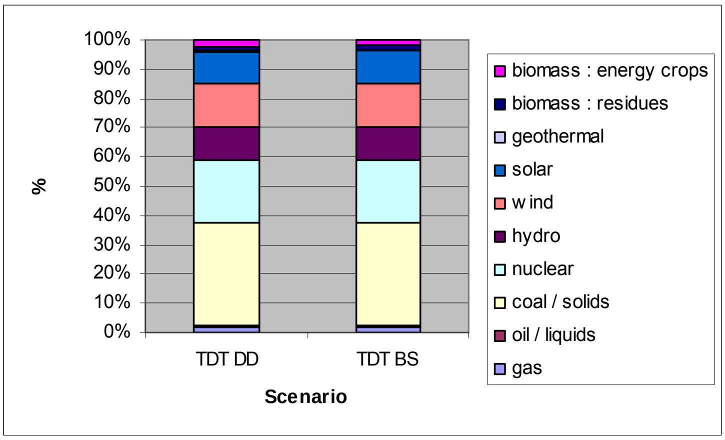

Figure A.1.6 Share of net electricity generation (TDT scenarios, 2050)

Table A.1.10 Electricity production (TWh) in the TDT scenarios (2050)

	TDT DD	TDT BS
Coal	0.0	0.0
Coal CCS	1677.8	1686.9
Oil	31.8	31.8
Gas	85.1	89.1
Nuclear	1020.0	1020.0
Hydro	553.4	554.0
Wind	706.6	707.0
Solar	537.9	537.9
Geothermal	10.5	10.5
Biomass energy crops	0.0	0.0
Biomass energy crops CCS	41.4	24.4
Biomass residues (waste + LFG)	136.0	136.4
Total	4800.5	4798.0

Concerning the transport sector the limitation of supply of relatively cheap biomass (compare the marginal costs of waste and wood chips in table 8 with the marginal costs of sugar beet) and the high prices of oil and gas, have resulted in the introduction of hydrogen and a large share of electricity (12%) in this sector. Due to a more limitation of biomass supply from forestry in the TDT BS scenario, a higher share for oil and gas is achieved in this scenario, compared to the TDT DD scenario (figure A.1.8).

Table A.1.11 presents the primary energy demand and contribution of biomass energy crops to it for the TDT scenarios. Also the contribution of energy crops to production of electricity and biofuels are reported. As can be seen the primary energy demand, as well as the contribution of biomass energy crops, are more or less the same in both scenarios. Also the amount of electricity generated in both scenarios is more or less comparable. However, the amount of biofuels in the TDT BS scenario is much less than in the TDT DD scenario. This difference (1852 PJ) is more or less equal to the higher demand for wood in households for the TDT BS scenario (2000 PJ, not included in table A.1.4, well included in table A.1.9). It has to be noticed that this additional wood for household heating is imported, so in TDT BS not the wood import as such is reduced, only the supply of wood chips from imported wood. These wood chips are used e.g. in power plants, but also in other energy conversion processes. Other possible sources of wood chips in the model are from straw, bark, and domestic timber (fiber chips). A comparison of the biomass supply (table A.1.4) and biomass demand (table A.1.9) shows, that in both scenarios a part of biomass potential (mainly from agriculture) has remained unused.

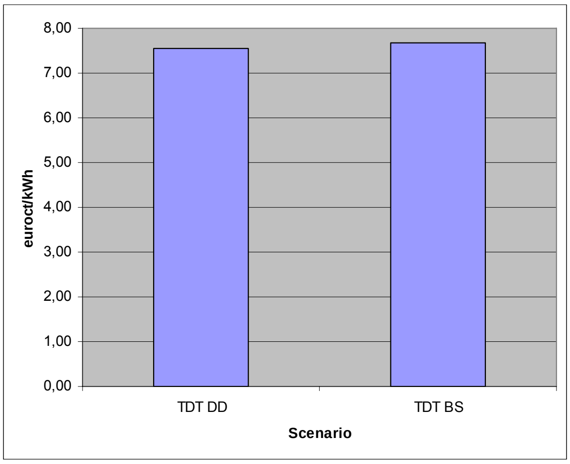

Figure A.1.7: Marginal cost of electricity mix (TDT scenarios, 2050)

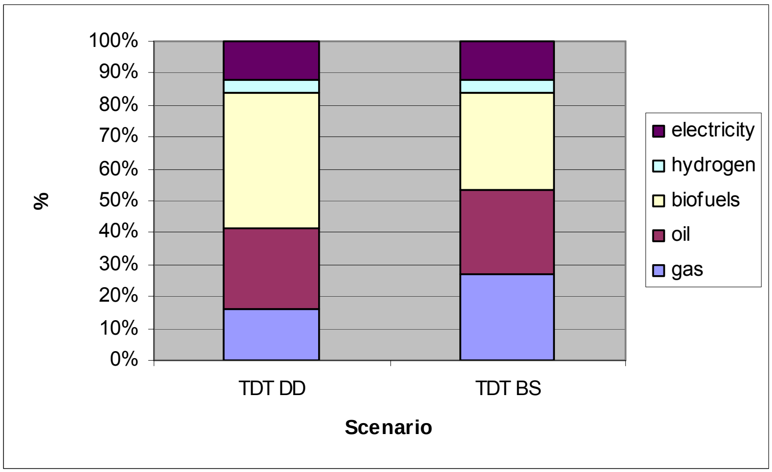

Figure A.1.8 Share of final energy demand in transport sector (TDT scenarios, 2050)

Table A.1.11 Primary energy demand and biomass energy crops (total and contribution to electricity / biofuel production) in the TDT scenarios

	TDT DD	TDT BS
Primary energy demand (PJ)	76531	76268
Biomass energy crops (PJ)	9368	9388
Electricity from biomass energy crops (TWh)	116	100
Biofuels (PJ)	6367	4515

Appendix 2 Analyses of biomass potentials with IMAGE

<to be added later>

Appendix 3 Biodiversity consequences of bio-energy use

A3.1 Introduction

The biodiversity effects of growing bio-energy crops are the response to several (global) environmental developments, both in the near and more remote future. On the short term, land-use dynamics are important, while on the long term (reduced) climate change comes in as well. Assessing these effects is surrounded with considerable uncertainty. The only study so far that integrally covered the biodiversity aspects of the biofuel debate is the scenario study performed for the 2nd Global Biodiversity Outlook (GBO2), discussed in the literature review (CBD and MNP, 2007). Therefore, this discussion of uncertainty aspects refers to the IMAGE-GLOBIO model chain and the biodiversity indicator of “naturalness” (MSA).

As the GLOBIO biodiversity model is located at the end of a chain of other models (Fig. 3.1.1.), uncertainties in all other models will influence uncertainty in the biodiversity response. Therefore, studying uncertainty should be tackled by integral modelling. For instance, the estimated potential for biomass production (par. 3.2 and 3.3) will determine the land-use dynamics. But at the same time, the many different relations and interactions between models and issues makes it difficult to make straightforward comparisons and draw clear conclusions. A careful experimental scenario design is necessary to make further progress with uncertainty analysis.

A complete biodiversity uncertainty assessment should ideally consider uncertainty in definitions (indicators), data uncertainty (land use data), model parameter uncertainty (climate responses), conceptual model uncertainty, and scenario assumptions. In the following, only a few aspects are briefly discussed and where possible quantified:

- Comparing scenarios, focusing on different land-use assumptions
- Land abandonment and biodiversity recovery
- Biofuel crops and local biodiversity values
- Indicator definition (MSA and other definitions)
- Climate change response functions in GLOBIO

A3.2 Some relevant uncertainties for biodiversity in biofuel assessments

Influence of agriculture productivity, land abandonment and biodiversity recovery

The scenario study for GBO2 includes a climate change mitigation option with a portfolio of measures, designed to reach the 450-ppm target for 2100. It includes an ambitious level for biofuel production (potential of 150 EJ from total energy use of 650 EJ; close to the maximum potential from cost calculations - Fig 3.2.1 – and in the mid range form the SRES scenarios – Fig 3.3.2). Compared to the GBO2 baseline, the option showed a negative biodiversity effect on the short term due to increased land-use. By 2050, this loss from land-use change was not yet compensated for by reduced climate change effects (Fig A.3.1 – left graph). The mitigation effects were the result of all measures and not due to biofuels alone. Up to 2100, more severe effects can be expected as climate change will de strongest then, but this time scale was not investigated.

In the GBO2 uncertainty analysis (see chapter 5 in CBD and MNP, 2007), it was mentioned that the baseline scenario contained an optimistic assumption on agricultural productivity increase. Combined with shifts in production areas, this led to land abandonment in several parts of the world (total of 4.5 million km^2). In the 450-ppm option, a considerable part of the abandoned land is used for woody biofuel production. This reduces the amount of nature that has to be converted for biofuel production.

In the upcoming OECD Environmental Outlook (OECD, in prep), a more modest productivity increase was assumed in the baseline. Now, abandonment occurs on a much smaller scale (1.7 million km^2), and agricultural expansion is considerable. In the 450-ppm climate change mitigation option, woody biofuel production was again ambitious. It is less than in GBO2, but is now combined with an even stronger agricultural productivity increase (compact agriculture). This leads to more abandonment in the option and reduced expansion, making room available for biofuel production. This way, further deforestation is prevented (and so is carbon loss from soils and biomass), which is an important element in reaching the 450-ppm target. The total effect of all measures is now favourable for biodiversity (see Fig A.3.1 – right graph).

This comparison shows that the balance between land-use for biofuel and reduced climate change is intimately related to scenario assumptions on agricultural productivity. The main difference between the studies is the implementation of a compact (intensive) agriculture: in the baseline for the GBO2 study versus in the option for the OECD study. Whether it is realistic to assume that biofuel production will stimulate agricultural intensification as applied in the OECD a study (through feed-back on for instance production prices), or that intensification is a process independent from biofuel production as was assumed in the GBO2 study, is an important subject for further research.

A point of criticism on the GBO2 study is the GLOBIO assumption that nature will completely restore on abandoned land in the baseline, with the consequence that biofuel production is compared to natural land-cover.

Several aspects and assumptions deserve further attention: likelihood of agricultural productivity increases, occurrence of land abandonment, and the role of biodiversity recovery in unused abandoned land.

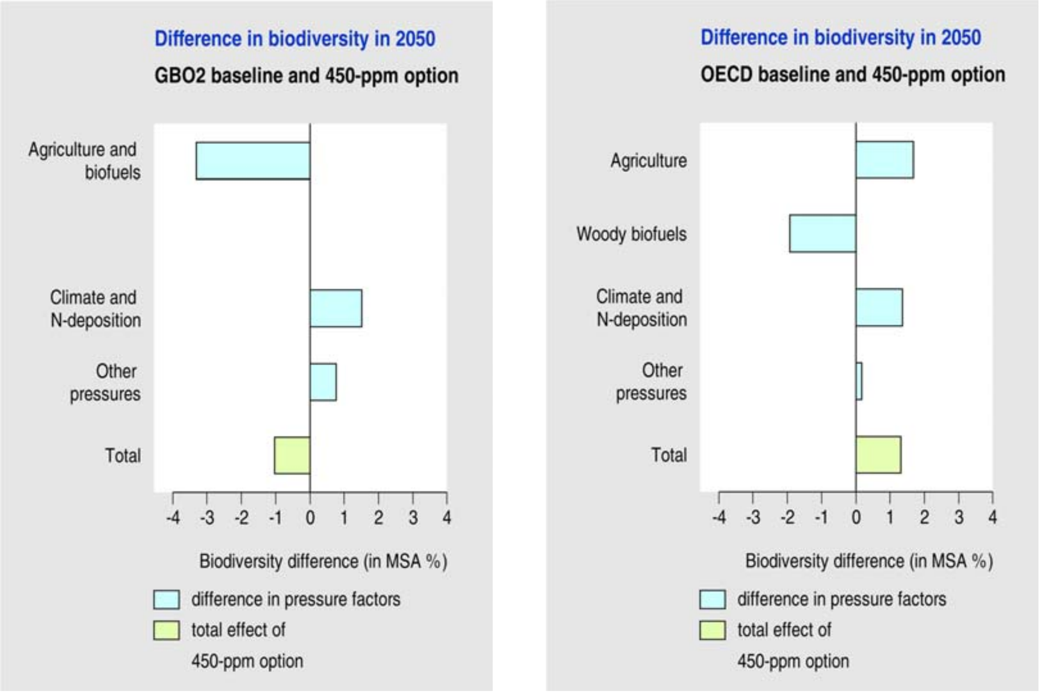

Figure A.3.1 Biodiversity differences for 2 different implementations of a 450-ppm climate change option. Left: GBO2 scenario (sCBD and MNP, 2007) and option. Right: OECD scenario and option (OECD, in prep).

A3.3 Influence of Model parameters and characteristics

With the scenario comparison as a background, the effect sensitivity of several model parameters can be investigated.

Biodiversity recovery on abandoned lands

An important assumption in the GBO2 baseline was the rapid recovery of biodiversity on abandoned agricultural lands by 2050. This influences the 450-option as abandoned land that is used for biofuel production is compared to the restored natural situation.

A new analysis of the GLOBIO literature database on secondary forest growth shows that a full recovery of biodiversity (in MSA) is not likely within 50 years (Fig A.3.2). A significant positive linear relation was noted for plant biodiversity only. Birds and other animals can recover much faster, but the variation and dynamics are large in the first (pioneer) stages of regrowth. In 50 years, biodiversity converges to an MSA value around 0.5. In a study on Bolivian tropical forests, the recovery of biodiversity to mature levels took about 40 years, as measured by total plant species numbers and the Shannon index. This suggests that the MSA indicator is more sensitive to the recovery process. Specific recovery of canopy species and their abundance may take more than 100 years. The long period for full recovery is the consequence of the complex vertical layered structure of especially tropical forests, and the slow growth rates of trees that dominate the climax situation (Peña-Claros, 2003).

Recovery in grassland ecosystems is probably faster than in forests, as their vertical structure is less complex. Due to but this could not be analysed with the literature contained in the current GLOBIO database.

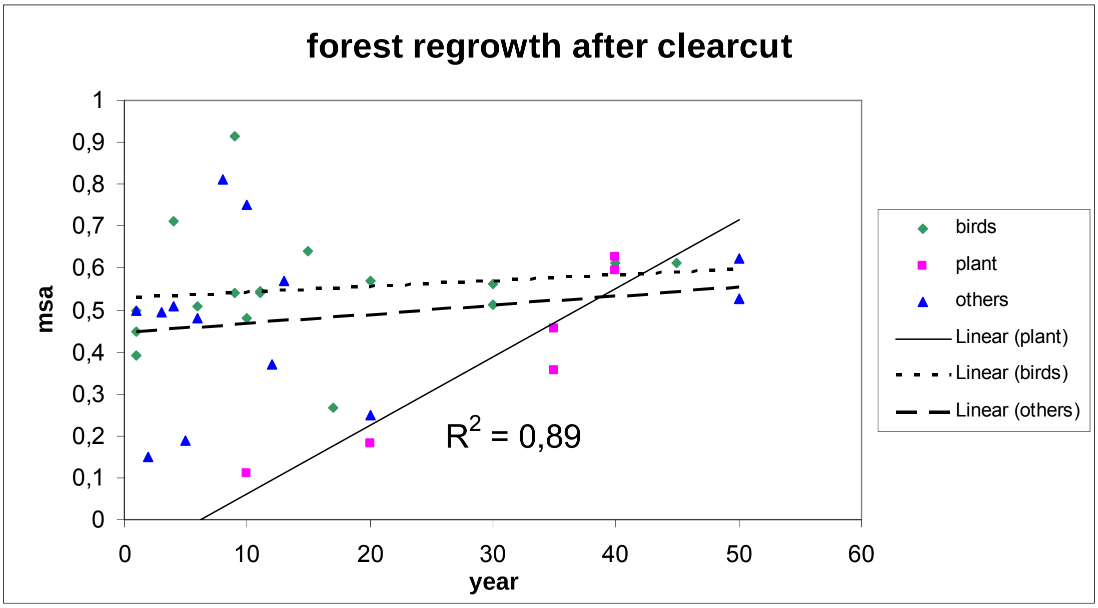

Figure A.3.2 Biodiversity values (as MSA) for different species during recovery after forest clearance. For plants, a significant linear relation was found. Each point presents a different published study, or plot from a sampled sequence (data from GLOBIO literature database).

Taking abandonment and potential recovery into account

In the GBO2 baseline, a total of 4.5 million km^2 of land used for agriculture in 2000 got abandoned and restored to nature by 2050 (mainly grasslands used for grass and fodder in East Asia, Russia, Oceania, the Middle East and Northern Africa). Assuming the slow forest recovery speed for all abandoned areas, the baseline loss should be 1.7% more by 2050[7] (towards 2100, this correction will be smaller as recovery continues). Assuming that all abandoned land is indeed available and used for biofuel production in the 450-ppm option, will turn the negative balance for the option into a net positive effect (+0.7%).

However, abandonment takes place in other regions than most biofuel production (through cost effects). A more detailed analysis of the GBO2 land-use dynamics shows that the abandoned

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[7] Calculation: (4.5 million x 0.5 km^2-MSA) relative to total a terrestrial surface of 132 million km^2.

area actually used for biofuel production in the option is about 1.9 million km^2, which presents a correction of +0.7% MSA[8]. The area of biofuels allocated on natural ecosystems (4 million km^2) results in considerable biodiversity loss (through conversion).

In the OECD scenario study, abandonment is much higher in the 450-ppm option than in the baseline (respectively 3.6 and 1.7 million km^2), due to the simultaneous development of a compact and productive agriculture. Now, 1.8 million km2 of abandoned area is used for biofuel production in the 450-ppm option. A correction for nature recovery is not necessary as the amount of biofuel fits into the additional abandoned area of the option. Another 3 million km^2 of natural areas is converted for the total biofuel production.

This limited exercise shows that biodiversity recovery can be a factor of importance for the net option effect, but only in scenarios where considerable abandonment takes place (for instance through trade liberalization or agricultural intensification). To fully assess the issue, the regional potential for and likelihood of biofuel production on abandoned and degraded areas should be taken into account. Further an extensive literature review on recovery in different ecosystem types (temperate and tropical forests, dry and humid grasslands) will give valuable additional information on recovery speeds.

Local biodiversity of different land-use types and crops

The local biodiversity value of land used for biofuel production depends on the actual crop and the applied management (intensity). Growing agricultural crops, such as maize or sugar cane, will result in locally low biodiversity values. In the GBO2 scenarios, values for wood plantations were used as proxy for woody biofuels. The question arises whether this is representative for ligneous, perennial plants and short rotation wood plantation.

To examine this, the database of reviewed literature was expanded and further separated into different categories. Perennial crops show mean MSA values around 0.3, which is comparable to wood plantations. Although there is a lot of variation between studies, the mean MSA values are known quite well (standard error of mean given in fig. A.3.3).

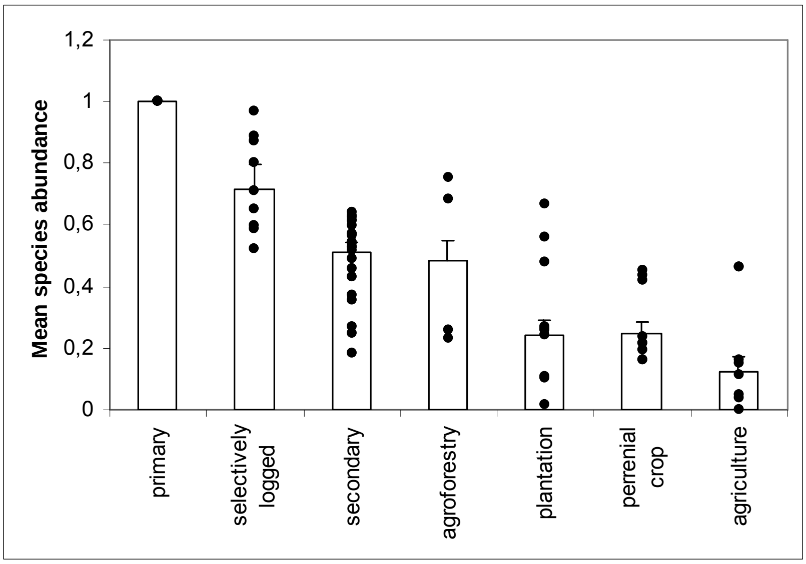

Figure A.3.3: Mean species abundance of original species for different land-use types that form a continuum in land-use intensity(from unimpacted forest to completely converted forest). Data from GLOBIO literature database.

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[8] Calculation: (1.95 million x 0.5 km^2-MSA) relative to total a terrestrial surface of 132 million km^2.

In both 450-options (GBO2 and OECD), mostly 2nd generation woody biofuels were grown (selected by TIMER). If these were replaced by 1st generation biofuels crops, local biodiversity values would be lower. Taking the same area as for woody biofuel production (about 6 million km^2 in GBO2), a shift to 1st generation would mean an additional global biodiversity loss of 0,9% (MSA) in the 450-options[9]. The MSA values for agro-forestry systems are higher than those for plantations and perennial crops, but the potential for biofuel production in these systems will probably not be high. Most of them are in use for valuable cash crops such as coffee and cocoa, but may be a source of local woodfuel supply.

Next to their biodiversity value, their net contribution to greenhouse gas emissions should be known for the different biofuel crops (see chpt 3.5). With both types of information, a balance between land-used and effective CO_2 reduction can be made. For this a life-cycle0-analysis type of indicator may be useful: $LCA_{biofuel} = \Delta CO_2$ /land-used.

Including species richness in the MSA indicator

An important characteristic of the MSA approach is the integration of different impacts in one and the same indicator. This allows comparing and balancing different pressures and time scales. But MSA is not sensitive to all aspects of biodiversity. For instance, it is not sensitive to the species richness of different biomes, as it uses indices relative to the natural state.

It is possible to partly include species richness by weighting. For the GBO2 scenario, weighting was done by multiplying the MSA values per cell with the number of natural species of the specific eco-region. Values were summed and processed for each geographical area that usually contains different eco-regions (sCBD and MNP, 2007).

With weighting, land-use changes and other pressures in species rich eco-regions and biomes are accentuated (tropical forests, Mediterranean grasslands, and temperate grasslands). The impacts of pressures at the global level are stronger, both in the baseline and policy options. The relative effect of options stays more or less the same. The overall decreasing values indicate that human impacts are greater in species-rich tropical and temperate zones than in species-poor boreal and Polar regions. The regional results change unexpectedly. Weighted MSA values are lower for all regions, except for South America, because the large species-rich Amazonian region remains relatively unimpacted. In conclusion, the option effects of GBO2 did not change significantly when applying weights per biome, other than the effects in the baseline scenario and options becoming somewhat larger. However, when pressures (such as land-use) shift from one region to another, more species rich regions, effects may be accentuated.

Modelling the biodiversity response to climate change

Global biodiversity studies can give very different results for future climate change effects (IPCC, 2007). This type of uncertainty is partly the consequence of using different models and concepts to explore the future mechanisms of biodiversity change, and different biodiversity definitions. Some examples will illustrate these different sources of uncertainty.

In a scenario study for the Millennium Assessment (van Vuuren *et al.*, 2006), the chance on ultimate global plant species extinction (at equilibrium, no specified year) was calculated. Up to 2050, the risk of extinction through climate change is between 2 and 4%. This result was obtained by using the species-area relationship for each distinguished biogeographical region, and relating that to the projected habitat loss. This approach treats the impacts of climate change (through shifting biome areas), and land-use change. In the species-area relationship, the definition of homogeneous areas is crucial, as the spatial level partly determines the strength of the response. In this case, the scale of “islands” was used that treats habitats as small islands in a human dominated landscape.

The GLOBIO modeling concept is based on the homogenization process that leads to changes in local abundance of species (= number of individuals per species) and ultimately local

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[9] Calculation: (6 million x 0.2 km^2-MSA) relative to total a terrestrial surface of 132 million km^2

disappearance of species, due to an array of pressure factors. In the GBO2 scenario study, the predicted biodiversity decline between 2000 and 2050 due to climate change was about 3% of the total decline of 7,5%. This is an indication of local change in species abundance, due to changing environmental conditions (temperature, rainfall and others). The 3% MSA loss through climate change can be visualized as the complete loss of all natural elements in an area the size of about 4 million km^2 (= 100 times the size of the Netherlands). It does not express the total, worldwide extinction of species. The climate change response is (surprisingly) close to the MA example. Both approaches look at low spatial levels, using land-use dynamics from the IMAGE model.

The temperature-biodiversity relationships used in the GLOBIO model are based on model runs in EUROmove (Bakkenes *et al.*, 2002, 2006). It applies the concept of climatic envelopes for species and calculates the stable areas (that will keep the same environmental conditions) under a scenario of temperature change, predicted by the HADCM3 climate model. Repeating this for a representative number of species per biome, gives fitted curves surrounded by statistical uncertainty (see Fig 3.4.5). The curve uncertainty is relatively small, due to the large number of species involved in the calculations. Applying different climatic models gives rise to more differences in responses (Bakkenes *et al.*, 2006).

So not only the biodiversity models will influence the uncertainty of the climate change response. A crucial element is the climate sensitivity itself, i.e. the response of climate variables to changes in the atmospheric CO_2-eq concentration. For the GBO2 study, it was assumed that the mean global temperature will increase by 2.5 K in response to a doubling of CO_2 equivalent atmospheric concentration. There is considerable uncertainty around this value. Current IPCC estimates range from less than 1.5 to 4.5 K, and recent literature suggests that even much higher values cannot be ruled out (see uncertainty section in sCBD and MNP, 2007). A low sensitivity implies that far less mitigation efforts are required to reach the 2 degrees target, lowering the pressure to convert land for bioenergy production. If the climate sensitivity turns out to be high, the beneficial effect of mitigation efforts is much lower and more measures are needed.

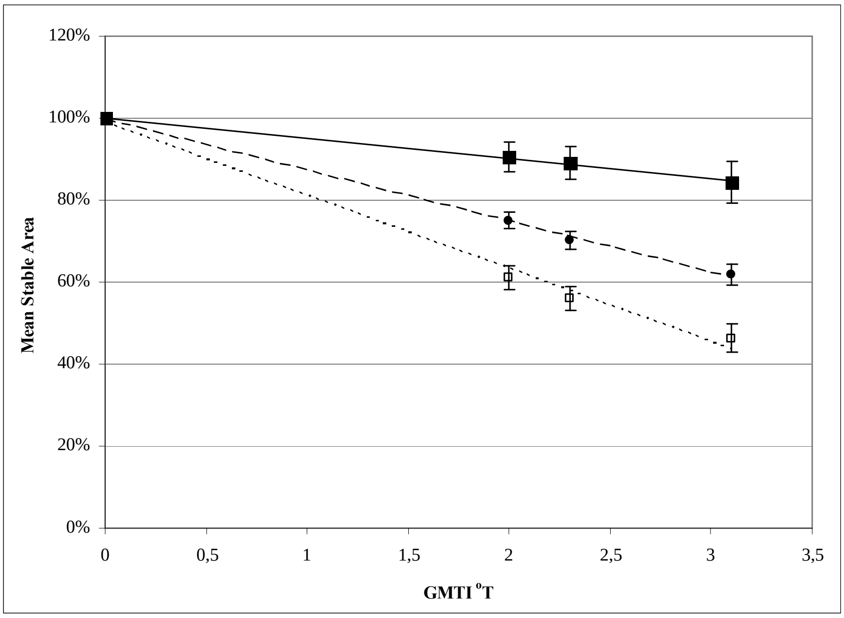

Figure A.3.4 Dose response relationships used for GLOBIO, describing the relation between global temperature change and the mean stable area of species in a specific biome. From top to bottom; tundra, temperate forest, grassland and steppe.

Combining different climatic models on temperature sensitivity, in combination with IMAGE and GLOBIO calculations could give further information on the sensitivity of the biodiversity response. Systematically covering all issues is an elaborate subject for further analysis. As a first estimate, the mentioned temperature range (1.5 to 4.5 K) can be taken as extreme values, and can be related to the calculated global 3% MSA response in the GBO2 baseline (at a baseline projection for ΔT of 1.85K by 2050). Assuming complete linearity and no further changes in natural areas will then lead to a range of temperature responses from 1.8% to 5.4% MSA[10].

Many other scenarios, models and indicators can be compared, and will undoubtedly show different results. The IPCC Working group III summarized the findings so far, and reported that 20 – 30% of all assessed species are at “increased risk of extinction”. Significant loss of biodiversity is projected for the future and covers a range of possible responses, at different spatial levels.

Differences between models and biodiversity indicators will not disappear with increasing research effort, but are inevitable given the complexity of the biodiversity issue, the different definitions, spatial levels, mechanisms of change, and time scales involved. This forms a type of irreducible uncertainty. In the CBD framework, the different approaches and indicators are therefore regarded as complementary sources of information, as they can show the importance of the different involved pressures and related policy actions.

Designing a new scenario to explore the effects of biofuel production
In the scenarios compared earlier, the interaction of biofuel production, land-use changes (abandonment, recovery), and the uncertainty of the climate response make it difficult to draw clear conclusions about the positive contribution of biofuel production to mitigating climate change and the biodiversity response.

A comparison between hypothetical scenarios with and without large scale biofuel production (and vice versa, less and more fossil fuel use), while keeping agricultural land-use the same, could shed more light on this question. These scenarios can also be used to explore some of the parameter, data and model uncertainties discussed above.

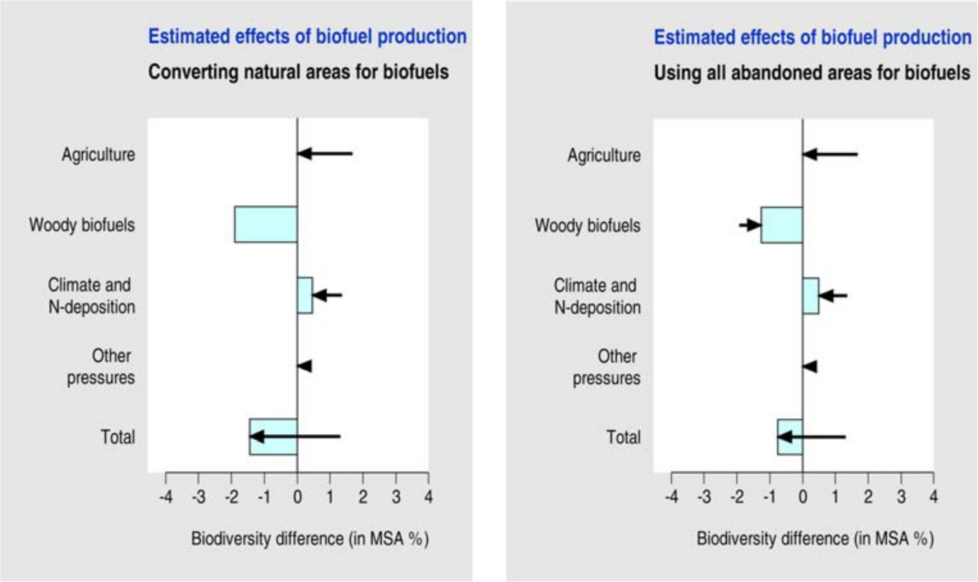

Fig A.3.5 Estimated effects of hypothetical biofuel scenarios. Left: effects of converting natural areas for biofue. Right: using all abandoned areas for biofuel production. Black arrows indicate corrections on the OECD 450-ppm option.

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[10] Calculation: 1.5/2.5 x 3% = 1.8% and 4.5/2.5 x 3% = 5.4%.

For instance, with the OECD 450-option as starting point, we can assume:

- the same amount of woody biofuels is produced
- agricultural land-use does not change (no additional abandonment or compact agriculture)
- about a third of the greenhouse gas emission reduction is brought about by biofuel production (net effect of woody biofuels), and will results in a third of the climate change response (assuming linear effects)

All biofuel production takes place in newly converted areas (maximum biodiversity loss) or all abandoned land is used for biofuels (effect with recovery correction). Taking the assumptions into account will lead to differences with the previously presented OECD 450-ppm option (see Fig A.3.5). The estimated differences are visualized with black arrows. For both biofuel land-use variants (all natural areas, or all abandoned areas), negative effects of biofuel production are noted for 2050. This is mainly the consequence of separating the climate change effects of biofuels only, and keeping agricultural land-use constant.

Including the uncertainty of climate sensitivity rages is not easily done, as with less sensitivity less biofuel will be needed. Exploring this source of uncertainty requires integrated modelling.

A3.4 Integration of results

With the presented and discussed sources of uncertainties and assumptions, a limited range of possible outcomes can be presented. The most important scenario uncertainty lies in the assumptions on agricultural land-use and the interaction with areas used for woody biofuels (only woody biofuels are treated here as most agricultural biofuels crops hardly contribute to greenhouse gas reductions).

Woody biofuels grown on natural areas, or completely grown on abandoned areas that would otherwise be available for nature restoration both lead to local biodiversity losses. When intensively managed agricultural areas are used for woody biofuels, local biodiversity will rise. However, these local effects neglect possible shifts in production to other areas.

Using agricultural biofuel crops will lead to higher local loses and hardly any wins for climate change, as their contribution to reducing greenhouse gas emissions is most probably low.

Table A.3.1Possibel ranges in biodiversity effects of growing woody biofuels. Extremes for different land-use variants are given. Further, extremes in climate change mitigation effects are given, based on uncertainty in climate sensitivity.

	GBO2 study	**OECD 2007 study**		
Woody biofuels area	6	4,7	million km2	
Different scenario on land-use change: extreme variants				
Woody biofuels instead of crops	+ 0,68%	+ 0,53%	global MSA	Neglecting trade-offs to other areas
Woody biofuels instead of recovered nature (50 years)	- 0,91%	- 0,71%	global MSA	Neglecting trade off to other areas
Woody biofuels instead of unaffected nature	- 2,73%	- 2,14%	global MSA	
Different climate change responses				
1.5 K	+or-1,8%	1,8%	global MSA	
2 K	3,0%	3,0%	global MSA	
4.5 K	4,5%	4,5%	global MSA	

Appendix 1 Use of degraded lands for biomass production

The use of degraded land for the production of biomass is often mentioned as a sound solution because of the absence of competition with other land uses, especially land used for food and animal feed production.

From, GLASOD, a global map on land degradation is known that large areas all over the world have been subject to land degradation or soil degradation (ISRIC, 1991). The map shows the type of soil degradation, the relative extend of the degradation, the degree of degradation and the severity. The total area of degraded soils is about 1964 million ha, which is about 15% of the total land surface. The four main types of soil degradation, in order of importance, are water erosion (56%), wind erosion (38%), chemical deterioration (12%) and physical deterioration (4%). The degradation is in almost all cases human induced. The most common causes of degradation are deforestation and removal of the natural vegetation, overgrazing, agricultural activities (improper management), overexploitation of the vegetative cover for domestic use and industrial activities leading to chemical pollution. Often, the topsoil, the layer with most of the nutrients, is affected (especially the case with water and wind erosion). Dependent on the degree of the degradation the soil might lose its function for food production or its function as substrate for natural vegetation. Reclamation of degraded soils into suitable land for production or into a natural vegetation is sometimes difficult and it takes a long time before the soils can support its anticipated function.

A light degree of soil degradation is identified for 38% of all degraded soils (750 million ha) and 46% has a moderate degree of soil degradation (910 million ha). Light means that there is a somewhat reduced productivity of the terrain, but manageable in local farming systems and moderate requires major improvements often beyond the means of the local farmers. Strongly degraded soils are not reclaimable at farm level and are virtually lost. Major engineering work or international assistance is required to restore these terrains. Extremely degraded soils are considered irreclaimable and beyond restoration. The strongly and extremely degraded soils together cover about 300 million ha.

It is difficult to assess the impact of soil degradation on the productivity of the soil. This depends on many local conditions. For example, a study by ISRIC on the impact of land degradation on food productivity in three different case studies (in Uruguay, Argentina and Kenya) shows a calculated yield reduction of about 25% - 50% after an erosion scenario of 20 years. In general one can conclude that yield levels on degraded soils are often far below the levels of the undisturbed soil. Restoration of the original vegetation on degraded soils has similar problems since most of the original conditions of the soil have been changed (lower nutrient levels, lower water holding capacity). It must be concluded that about the potential of these soils not much is known.

In the discussion on the potential of using degraded soils for biomass. The efforts required to reclaim these areas and the lower productivity of these soils must be considered very seriously. For moderately degraded lands this means financial support to the farmers, which in some cases might be considered for strongly degraded lands as well. Obviously, this is a rather general observation. The real potential strongly depends on the local condition, including other local benefits, and must be based on local potential studies.

Currently, the reclamation of degraded soils is aiming mostly at restoring the function to produce food in combination with avoiding further degradation or avoid adjacent problems (downstream silt problems). In future reclamation plans it is likely that other targets, which are linked to climate change policies, become more and more appropriate. The use of degraded soils for biomass production and the use of degraded soils for increasing the carbon stock in soil and/or vegetation are examples of realistic mitigation options. Activities undertaken to reclaim degraded soils should preferable consider all options mentioned and be planned and executed in close cooperation.