CLIMATE CHANGE

SCIENTIFIC ASSESSMENT AND POLICY ANALYSIS

Biomass Assessment

Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy: Inventory and analysis of existing studies

Supporting document

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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1 Introduction

This Supporting Document contains the result of the inventory phase of the study: "*Biomass Assessment: Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and materials*". The study was commissioned and supported by the Netherlands Research Program on Climate Change (NRP-CC), subprogram Scientific Assessment and Policy Analysis (WAB).

Main objectives of the 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.

Part 1 is reported in this Supporting Document, while Part 2 and 3 are covered in the Main Report of the study.

Consortium

The study is carried out by a consortium consisting of:

- Utrecht University (UU)
- Vrije Universiteit Amsterdam (VU),
- Wageningen University and Research centre (WUR),
- Netherlands Environmental Assessment Agency (MNP),
- Energy research Centre of the Netherlands (ECN),
- Utrecht Centre for Energy research (UCE, manager).

Structure of the report

The main structure of the report is based upon the key areas selected:
Chapter 2: Biomass potentials
Chapter 3: Food demand
Chapter 4: Water
Chapter 5: Biodiversity
Chapter 6: Demand-side models
Chapter 7: Agricultural economics

This draft is being circulated for comments to the members of the Dutch Sounding Board of the project and also to the members of the international Review Group.

2 Biomass potentials

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2.1 Summary of biomass potential studies review

2.1.1 Introduction

Targets and projections for the contribution of biomass to the energy supply go up to over 30% of the global energy demand in the first half this century and even more after that. Thus, the expectations on the contribution of biomass to energy production are high. Moreover, biomass is expected to play a larger role in the provision of materials, such as chemicals and construction materials. To evaluate these expectation and to develop adequate biomass utilization strategies, various assessments of the amount of biomass that can be used for energy and material purpose in the short to long term have been carried out. However, 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. In the case of economical potentials ranges were also based on differences in the estimated production costs.

Biomass can be divided into *biomass from primary production*, *primary residues (*i.e. harvest and logging residues), *secondary residues* (i.e. residues from the processing of agricultural crops and wood products) and *tertiary residues (*i.e. residues after end-use of biomass products. The studies assessed deal with either technical or economic biomass potentials:

- Technical potential, i.e. the theoretical upper potential limited by the demand of land for other purposes and based on an assumed level of agricultural technology.
- Economic potential, i.e. the technical potential limited by economic profitability. The economic potential is determined by biomass production costs that are a result of land prices and production systems (i.e. supply costs) as well as by the demand for crops and wood products.

2.1.2 The ideal study

An 'ideal' study to evaluate technical biomass potentials should take into account global and regional trends such as land use, food demands, GDP growth and population development. In addition to that many factors that determine land availability or crop yields depend on very *specific local conditions* that play a large role in determining regional biomass potentials and might be even more important in the overall results. Such local conditions are soil types, water availability, possibility of irrigation and land use planning taking biodiversity and soil quality into account. Biomass potentials have been analyzed at different geographical scopes. Most assessment studies use either regional data or grid-cell data (1°x1°), but local conditions have not been analyzed in a sufficient detail, which might lead to over- or underestimation of local biomass potentials that could add up on the global scale.

In view of economic potentials, biomass production costs in relation to energy and/or carbon prices are decisive, which in turn depend directly on the supply and demand of food, materials, wood products and energy carriers. Increasing the use of biomass for energy and materials, however, would change land-use patterns and energy systems significantly. Such changes influence supply and demand of (agricultural) land as well as supply and demand 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, have been underexposed in biomass potential studies. As a consequence, economic biomass potentials may be overestimated as price increases are not taken into account or underestimated as adaptation in the supply of biomass and food (e.g. intensification) are not considered.

2.1.3 Review of recent studies estimating biomass potentials

Earlier, the 'GRAIN project' assessed 17 studies that estimated biomass potentials. This assessment concluded that "the studies arrived at widely different conclusions about the possible contribution of biomass in the future global energy supply (e.g., from below 100 EJ yr^{-1} to above 400 EJ yr^{-1} in 2050) and that the major reason for the differences is that the two most crucial parameters—land availability and yield levels in energy crop production—are very uncertain, and subject to widely different opinions" (Berndes et al., 2003)

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, economic mechanism that influence potentials if the use of biomass is applied on a large scale and on the relationship with biodiversity. For this purpose, we analyzed 8 recent studies. Of the recent studies available, we selected those that either estimate global biomass potentials and/or that developed methodology further. Special attention in review of biomass potential studies is paid to the methodology and data used to include the above mentioned issues. None of the studies regarded does cover the whole range of issues, but have strong points at certain aspects of the relation between biomass potentials and issues like, food, water and economy. Table 2.S1 summarizes the strong and weak points of the studies reviewed.

Table 2.S1 Overview and evaluation of selected biomass potential studies

Study	**Subject**	**Biomass potential**	**Evaluation**
Fischer et al., 2005	Assessment of eco-physiological biomass yields	CEE, North and Central Asia; EC (poplar, willow, miscan-thus); TP	*Strong:* detailed differentiation of land suitability for biomass production of specific crops on a grid cell level (0.5 degree) *Weak:* not considering interlinkages with food, energy, economy biodiversity and water demands
Hoogwijk et al., 2005	Integrated assessment based on SRES scenarios	Global, EC (short rotation crops); TP	*Strong:* integrated assessment considering food, energy material demands including a scenario analyses based; analyses of different categories of land (e.g. marginal, abandoned) *Weak:* crop yields not modelled detailed for different species and management systems
Hoogwijk et al., 2004	Cost-supply curves of biomass based on integrated assessment	Global; EC (short rotation crops; TP, EP (as cost-supply curve)	*Strong:* establishes a global cost-supply curve for biomass based on integrated assessment *Weak:* linkage land/ energy prices not regarded
Obersteiner et al., 2006	Biomass supply from afforestation/ reforestation activities	Global; F (incl. short rotation); EP	*Strong:* modelling of economic potential by comparing net present value of agriculture and forestry on grid-cell level *Weak:* yields of forestry production not dependent on different technology levels
Perlack et al., 2005	Biomass supply study based on outlook studies from agriculture and forestry	USA; EC, F, FR, AR, SR, TR; TP	*Strong:* detailed inclusion of possible advances in agricultural production systems (incl. genetic manipulation) *Weak:* no integrated assessment, e.g. demands for food and materials not modelled
Rokityanski et al., 2007	Analysis of land use change mitigation options; methods similar to Obersteiner et al., 2006.	Global; F (incl. short rotation); EP	*Strong:* policy analysis of stimulating land use options including carbon prices *Weak:* agricultural land not included
Smeets et al., 2007	Bottom-up assessment of bio-energy potentials	Global; EC, F, AR, FR, SR, TR; TP	*Strong:* detailed bottom-up information on agricultural production systems incl. animal production *Weak:* yield data for crops only regionally modelled
Wolf et al., 2003	Bottom-up assessment of bio-energy potentials mainly analyzing food supplies	Global; EC; TP	*Strong:* various scenarios on production systems and demand showing a large range of potentials *Weak:* yields of energy crops not specified for different species and land types

Biomass: EC – energy crops, F: forestry production, FR: primary forest residues, AR: primary agricultural residues, SR: secondary residues, TR: tertiary residues : Potentials: TP – technical potential, EP – economic potential

2.1.4 Resulting data for key parameters

The scope in terms of biomass resources included as well as the scenario assumptions vary between the different studies. As a consequence, global biomass potentials vary widely, see Figure 2.S1. The high biomass potential for 2050 determined by (Smeets et al., 2007) shows possible potentials that arise with an intensification of agriculture assuming a very high technological level of agricultural production. On the contrary, the low biomass potential for 2050 calculated by (Wolf et al., 2003) represent a pessimistic scenario with regard to population growth, to food demands and assuming a low intensive ('ecological') production system. The study of (Hoogwijk et al. 2005) regards the production of energy crops on abandoned, marginal and restland assuming global and regional trends as described in the IPCC SRES scenarios, while an increase in agricultural efficiency over time is assumed. This leads to estimated biomass potentials that are higher in 2100 than in 2050, especially in the scenario that assumes a large development of agricultural management systems. The highest potentials in this study result for the A1 scenario, while the lowest potentials occur in the A2 scenario. This is also true for the economic potentials estimated in (Hoogwijk et al., 2004.) Finally, the study of (Rokityanski et al., 2007) determines economic potentials of biomass production from afforestation and reforestation, thus, excluding other energy crops and secondary and tertiary residues and assuming extensive forestry management. As a result, the economic potentials for 2100 are rather low.

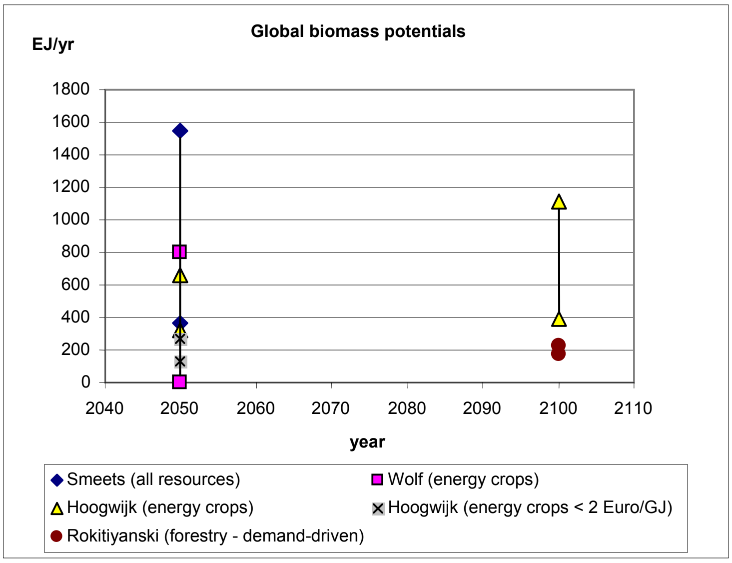

Figure 2.S1 Ranges of estimated global biomass potentials

2.1.5 Conclusions

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. Furthermore, a large part of important methodological and data issues remain unresolved in the recent studies even though often more knowledge is available in other scientific disciplines as has been shown in other part of the assessment, i.e. assessment on the knowledge base in the fields of water, food, biodiversity, energy demand and economic mechanisms. Important issues are:
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 possible protein chains have been poorly included in the potential estimates, while the impacts of different animal production systems could be studied in more detail and applied to more biomass potential studies
- Crop yields due to different agricultural production system have a large impact on biomass potentials (Perlack et al., 2005; Smeets et al., 2007), but more knowledge on the expected

rates of learning and implementation of advanced technologies in agriculture would be desirable.
- 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.

Further research on specifying yields of food crops, energy crops and forestry depending on detailed local conditions, water availability and developments of agricultural technology seems not sufficient. Also research on the competition between biomass for energy and materials with food, wood products and other energy carries as well as competition for water and land resources is necessary.

2.2 Introduction

Biomass is considered to be the most important renewable energy source for the coming decades, worldwide, in Europe, as well as in the Netherlands. Targets and projections for the contribution of biomass to the energy supply go up to over 30% of the global energy demand in the first half this century and even more after that. The Netherlands also formulated a vision that 30% of the national energy supply should be covered by biomass in 2030 which is equivalent to about 1000 PJ.

Thus, the expectations on the contribution of biomass to energy production are high. Moreover, biomass is expected to play a larger role in the provision of materials, such as chemicals and construction materials. To evaluate these expectations and to develop adequate biomass utilization strategies, various assessments of the amount of biomass that can be used for energy and material purpose in the short to long term have been carried out.

Biomass potentials in various studies are often expressed in EJ per year. However, the types of biomass regarded as well as the type of potential investigated vary. It is, therefore, important to define the terms ‘biomass’ and ‘potential’ carefully.

Biomass can be divided into *biomass from primary production*, *primary residues*, *secondary residues* and *tertiary residues*, see Figure 2.1.
- Biomass from primary production are energy crops that are grown on agricultural land and wood produced in forests. It should be noted, that short rotation crops are sometimes referred to as forestry and sometimes referred to as energy crops
- Primary residues are residues from harvesting, i.e. agricultural residues (e.g. wheat straw, bagasse) and forestry residues (e.g. small branches and tops).
- Secondary residues arise during the processing of agricultural crops and wood products to produce food/fodder and other materials, e.g. oilseed cake or sawmill dust
- Tertiary residues are residues after end-use of biomass products, e.g. wood from demolition waste or sewage sludge.

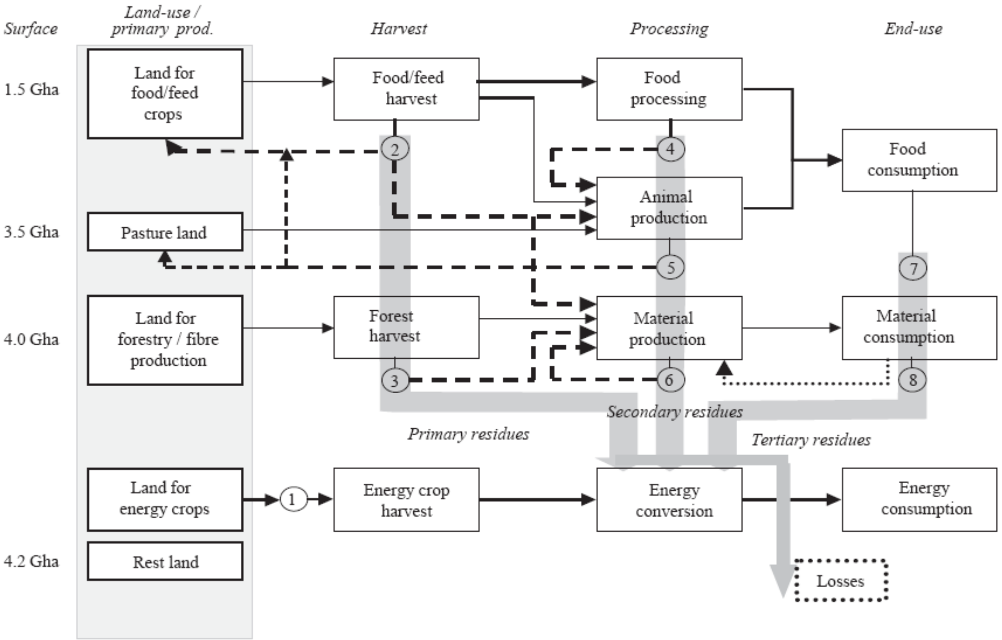

Figure 2.1 Overview of various present types of biomass flows and the global land surface (Hoogwijk et al., 2005)

Biomass potentials can be divided into *technical, economic* and *implementation potentials*.

- Technical potential, i.e. the theoretical upper potential limited by the demand of land for other purposes and based on an assumed level of agricultural technology. The technical potential depends mainly on crop yields, land and forest areas available for biomass production and the demand for food and wood products. Crop yields depend on agro-ecological data (e.g. climate, soils) and the level of agricultural technologies
- Economic potential, i.e. the technical potential limited by economically profitability. The economic potential is determined by biomass production costs that are a result of land prices and production systems (i.e. supply costs) as well as by the demand for crops and wood products. Economic potentials can change with the amount of biomass produced, e.g. land prices may rise due to an increased use of biomass for energy.
- Implementation potential, i.e. the economic potential that can be implemented within a certain time frame. Implementation potentials depend on technological learning and the drivers and barriers that influence innovation. In many assessment studies a considerable progress in agronomy (and forestry) is assumed leading to higher yields in the future. Whether or not, this improvement of yields and costs will take place, is a key question in assessing future biomass potentials.

2.3 The ideal study

Earlier, the ‘GRAIN project’ assessed 17 studies that estimated biomass potentials. This assessment concluded that “the studies arrived at widely different conclusions about the possible contribution of biomass in the future global energy supply (e.g., from below 100 EJ yr^{-1} to above 400 EJ yr^{-1} in 2050) and that the major reason for the differences is that the two most crucial parameters—land availability and yield levels in energy crop production—are very uncertain, and subject to widely different opinions” (Berndes et al., 2003) Moreover, this assessment concluded that the links of biomass potentials with food production, biodiversity, soil and nature conservation, and carbon sequestration have not been analyzed sufficiently.

Smeets et al. (2007) divided biomass potential studies into *demand-driven*, *supply-driven* and *demand-supply driven* studies. Most of the reviewed biomass potential studies are either demand- or supply driven, i.e. they analyze the competitiveness of bio-energy or that focus on the total bio-energy resource base. An ‘ideal’ study, however, should take into account the *economic relationships between the demand and the supply of biomass*.

For *supply driven* studies estimating technical potentials main parameters are crop and forests yields, agro-ecological data, water availability, population growth in terms of the demand for food and wood products, the establishment of forest plantation and the rate of improvement in agricultural management and the use of pastures and marginal land for biomass production., see Figure 2.2 for a possible approach that takes into account the different demands for biomass resources.

Biomass potentials have been analyzed at different geographical scopes. Most assessment studies use either regional data or grid-cell data (1°x1°). However, many factors that determine land availability or crop yields depend on very *specific local conditions*, such as soil types, water availability, possibility of irrigation and land use planning taking biodiversity and soil quality, These local conditions have to be taken into account. Conditions for improving crop yields as well as allocation of land to biomass and food production remain critical issues that have to be resolved. Environmental concerns such as water pollution and availability, soil erosion and quality and bio-diversity may limit technical potentials.

For *demand-driven* studies estimating economic potentials, economic growth, carbon prices and energy demands are crucial parameters determining potential, see the Section 6 for a further discussion of critical issues.

Finally, *demand-supply driven* studies are often so-called ‘integrated assessment’ studies. Apart from the parameters that are important for supply and demand driven studies, this type of study should incorporate links between the supply and demand. Here, biomass production costs in relation to energy and/or carbon prices are decisive, which in turn depend directly on the supply and demand of food, materials, wood products and energy carriers. Increasing the use of biomass for energy and materials, however, would change land-use patterns and energy systems significantly. Such changes influence supply and demand of (agricultural) land as well as supply and demand 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 using price elasticities, have so far been underexposed in biomass potential studies.

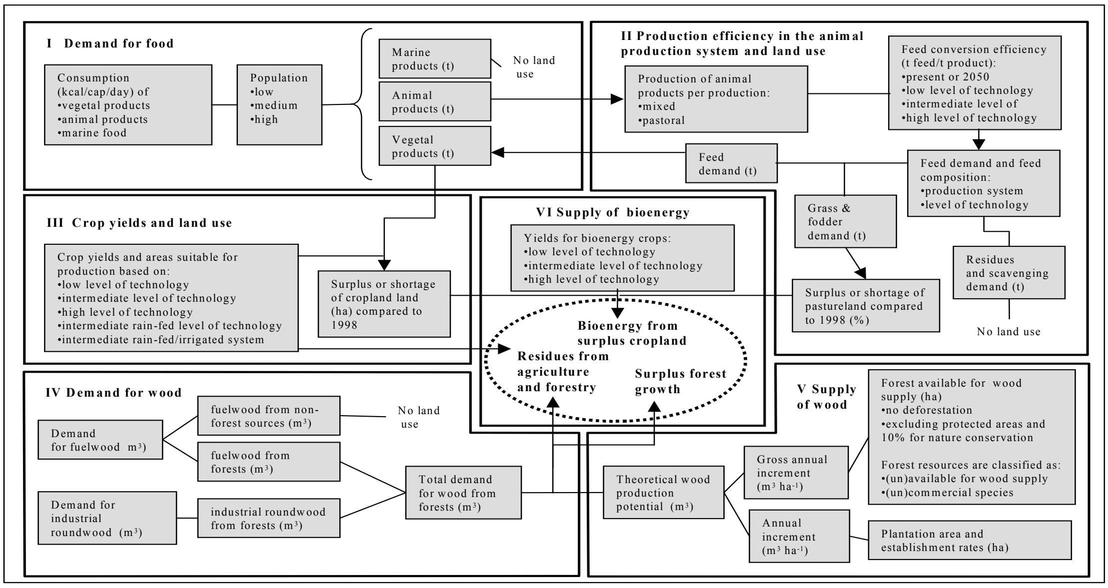

Figure 2.2 Overview of key elements and correlations included in the assessment of (Smeets et al., 2007).

2.4 Review of recent studies estimating biomass potentials

In this review, we will focus on the relation between estimated biomass potentials and the availability and demand of water, the production and demand of food, economic mechanisms that influence potentials if the use of biomass is applied on a large scale and on the relationship with biodiversity. These aspects will be discussed in detail in the next two sections analyzing recent studies that estimate biomass potential.

2.4.1 Overview studies

Since the GRAIN assessment of biomass potential studies (Berndes et al., 2003), a couple of new biomass potential studies have been published. For our overview, we selected studies that either focus on an assessment of global biomass potentials in the next 0 to 50 years (or even 100 years) and/or developed methodology to estimate potentials taking into account local conditions. Other non-selected recent biomass potential studies are presented in appendix 2.

Table 2.1 summarizes the main characteristic of the 8 studies selected for our review, a more detailed overview of the studies is given in appendix 1. As our research focus of this part of the review are the amounts of biomass that are potentially available in the future, most selected studies are supply-driven. Demand-driven studies that specify the use of biomass for energy have been discussed in the section 'energy and biomass demand projections.) However, Obersteiner et al. (2006) and Rokityanski et. al. (2007) use a partly supply-demand driven approach starting from a competition between agriculture and forestry depending on carbon prices.

Table 2.1 Overview of selected biomass potential studies

Study	Subject	Regional scope	Type biomass	Type potential	Strong points	Weak points
Fischer et al., 2005	Assessment of eco-physiological biomass yields	CEE, North and Central Asia	EC (poplar, willow, miscanthus)	TP	- good differentiation of land suitability for biomass production of specific crops on a grid cell level (0.5 degree) - modeling more detailed than in previous assessments using land suitability	- pure supply study based on eco-physiological characteristics - not considering interlinkages with food, energy, economy biodiversity and water demands
Hoogwijk et al., 2005	Integrated assessment based on SRES scenarios	global	EC (short rotation crops)	TP	- integrated assessment considering food, energy material demands - scenario analyses based on economic developments - analyses of different categories of land (e.g. marginal, abandoned)	- crop yields not modeled detailed for different species and management systems - economic potentials are not regarded as well as linkage land/energy prices
Hoogwijk et al., 2004	Cost-supply curves of biomass based on integrated assessment	global	EC (short rotation crops)	TP, EP (as cost-supply curve)	- establishes a global cost-supply curve for biomass based on integrated assessment	- economic potential is not quantified depending on energy prices - linkage land/ energy prices not regarded
Obersteiner et al., 2006	Biomass supply from afforestation/ reforestation activities	global	F (incl. short rotation),	EP	- modeling of economic potential by comparing net present value of agriculture and forestry on grid-cell	- agricultural land not included - yields of forestry production not dependent on different

Study	Subject	Regional scope	Type biomass	Type potential	Strong points	Weak points
					level	technology levels
Perlack et al., 2005	Biomass supply study based on outlook studies from agriculture and forestry	USA	EC, F, FR, AR, SR, TR	TP	- includes all biomass resources - detailed inclusion of possible advances in agricultural production systems (incl. genetic manipulation)	- no integrated assessment, e.g. demands for food and materials not modeled
Rokityanski et al., in press	Analysis of land use change mitigation options; methods similar to Obersteiner et al., 2006.	global	F (incl. short rotation),	EP	- policy analysis of stimulating land use options - carbon prices explicitly included	- agricultural land not included - no technical potentials analyzed additionally to economic potentials
Smeets et al., 2007	Bottom-up assessment of bio-energy potentials	global	EC, F, AR, FR, SR, TR	TP	- detailed bottom-up information on agricultural production systems incl. animal production - complete overview of resources	- no economic potential or costs calculated - yield data for crops only regionally modeled
Wolf et al., 2003	Bottom-up assessment of bio-energy potentials mainly analyzing food supplies	global	EC	TP	- bottom-up analysis of food production - various scenarios on production systems and demand showing a large range of potentials	no economic potential or costs calculated - yields of energy crops not specified for different species and land types

Biomass: EC – energy crops, F: forestry production, FR: primary forest residues, AR: primary agricultural residues, SR: secondary residues, TR: tertiary residues :
Potentials: TP – technical potential, EP – economic potential

2.4.2 Approaches used in the studies

2.4.2.1 Water

Water supply and demands of crop production and other water uses have been taken into account in a very simplified way in the regarded models. Most studies estimated yields by agro-ecological zones (AEZ) or crop growth models, which in turn are based on net primary production. In addition, Fischer et al. (2005) modelled water limitations of crop growth explicitly by comparing climate data with evapotranspiration data of specific crops, i.e. miscanthus, poplar and willow. All these approaches take into account rain-fed yields but do not include irrigation.

Some studies also include assumption on irrigation, but most studies specify irrigation only indirect, i.e. by using management factors (Hoogwijk et al., 2005; Hoogwijk et al., 2004) or by assuming the current agricultural system that includes irrigation (Perlack et al., 2005). Management factors do specify the relation of actual yield to theoretical rain-fed yield, however, it has not been specified whether this relation is based on the application of irrigation or other management measures, e.g. fertilization. Two studies analyze irrigation more directly, but do not distinguish between different technologies and water availabilities due to other (industrial) water uses. Smeets et al. (2007) analyze whether soil, climate and terrain are suitable for irrigation based on AEZ and assumes irrigation on suitable areas only, while Wolf et al. (2003) estimate the possibility of irrigation on a grid-cell level.

2.4.2.2 Food demands and agricultural production

The land needed for food production is essential to calculate biomass potentials for energy and materials and as such food demand is included in all potential studies that regard agricultural land. Approaches to estimate the amount of land that is required to provide food demands range from the use of simple key figures to integrated assessment models. For example, Fischer et al. (2005) exclude land highly suitable for cereals for biomass production without linking to actual food demands, while Hoogwijk et al. (2005) model food demands in an integrated assessment model taking into account supply and demands. Also food demands are based on diets related to GDP (Perlack et al., 2005; Smeets et al, 2007). Exceptions are the studies investigating forestry options (Obersteiner et al., 2006; Rokityanski et al., 2007). Here, food demands are not taken into account, but afforestation and reforestation are applied where the NPV of forestry is higher than the NPV of agricultural production.

Diets are based mainly on FAO projections and population estimates and many studies differentiate food demands between animal products and vegetal products (Hoogwijk et al., 2005; Hoogwijk et al., 2004; Smeets et al., 2007; Wolf et al., 2003). Modelling of agricultural crops ranges from modelling only grains and pastures (Wolf et al., 2003) to a differentiation of many different types of crops and fodder (Hoogwijk et al., 2005; Smeets et al., 2007). Sources of proteins for human consumption are not further researched.

Concerning food and energy crop production, most studies define different input and technology levels –e.g. ‘high input’ and ‘low input’ without specifying management methods such as the amount of fertilizers, type of machinery, etc. Approaches are the use of management factors which have been defined within the IPCC SRES scenarios (Hoogwijk et al., 2005; Hoogwijk et al., 2004) the modelling of production costs from a top-down approach (Obersteiner et al., 2006; Rokityanski et al., 2007) and the more detailed definition of a variety of relative high input systems (Smeets et al., 2007).

The efficiency of agricultural production increases over time in most studies, however, the resulting yields differs considerably. Hoogwijk et al. (2005) assume for the year 2100 management factors of up to 1.3, while Perlack et al. (2005) assume yield increases of 25 to 50% for the U.S and Smeets et al. (2007) even assume yield increases by a factor 2.9 - 4.6 in the world.

2.4.2.3 Material and energy demands

Material demands in general are not included in detail in the biomass potential studies. Only Smeets et al. (2007) and Perlack et al. (2005) include the processing residues from the production of food, bioenergy and wood products as well as waste using demand projections for the future from literature.

The demand for wood products is included in some studies as it determines the availability of forest resources for bio-energy. Hoogwijk et al. (2005) model the demand for wood using the integrated assessment model IMAGE, Smeets et al. (2007) use different levels of wood demands derived from literature in a scenario analysis and Perlack et al. (2005) estimate wood demand from macro-economic parameters.

Apart from the use of processing residues for bio-energy production, the selected studies do not consider the energy use of biomass as they are supply-driven. Obersteiner et al. (2006) use energy and carbon prices from the MESSAGE model to generate NPVs of afforestation

2.4.2.4 Economic mechanisms

Economic interactions that determine biomass potentials can be described at three different levels:

1. A comparison of production costs of different alternatives (e.g. different crops or forestry) at the farm level (micro-economic)
2. A comparison of biomass supply costs with demand curves and the resulting potentials
3. Changes of demand and supply curves due to income and substitution elasticity, e.g. changing land and food prices caused by increased bio-energy production.

Only two studies regard the production costs at the micro-level, i.e. these studies compare the net present value of agriculture to the net present value of forestry for carbon sequestration and biomass production (Obersteiner et al., 2006; Rokityanski et al., in press). In this way, competition for land is modeled. In the other studies, biomass production does not depend on the benefits for the producer as biomass production is supply driven.

Hoogwijk et al. (2005) use the Integrated Assessment Model IMAGE that has an agricultural economy model, which models food demand depending on GDP, population, etc. and at the same time models according supplies. Biomass for material and energy production is not modelled on the basis of demand and supply curves, but Hoogwijk et al. (2004) establish a global supply curve for biomass.

With regard to land prices, Hoogwijk et al. (2004) use scenario dependent land rental costs and Obersteiner et al. (2006) and Rokityanski et al. (2007) apply geographically specific land prices. However, these land prices do not depend on the level of biomass production. Food prices are not specified at all in the studies regarded.

None of the studies models the demand and supply for biomass for energy and material on the third level, i.e. using elasticity to describe a relation to food and wood product demand dynamically. In some studies explicitly modelled energy and carbon prices that are derived from the energy model MESSAGE are used to describe afforestation/reforestation supply approach (Obersteiner et al., 2006; Rokityanski et al., 2007).

2.4.2.5 Biodiversity

Several studies exclude the use of certain land areas for the production of biomass for biodiversity reasons, i.e. by using land claim exclusion factors for all types of land (Hoogwijk et al., 2005; Hoogwijk et al., 2004) and by excluding protected areas (Perlack et al., 2005, Smeets et al., 2007). Moreover, Fischer et al. (2005) exclude the use of forest land from biomass production, but does not mention biodiversity as a specific reason for this exclusion. Rokityanski et al. (2007) do not exclude forest land from biomass production, but discourages deforestation using a carbon policy.

Another way of including biodiversity, is the assumption of low-intensive production systems, i.e. assuming forestry with a low intensity (Rokityanski et al., 2007), keeping the use of pastures constant to avoid increasing grazing intensities (Smeets et al., 2007) and assuming a very low-intensive agricultural production system in a scenario analysis (Wolf et al., 2003). However, none of the regarded studies evaluates the effect of biomass production and the proposed measures on biodiversity.

2.4.2.6 GHG 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. 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 possible involved and the fossil reference system; see also Figure 2.3. In general, second generation biofuels are more favourable than first generation biofuels as they tend to reduce energy inputs into biomass production and to increase the efficiency of biomass conversion.

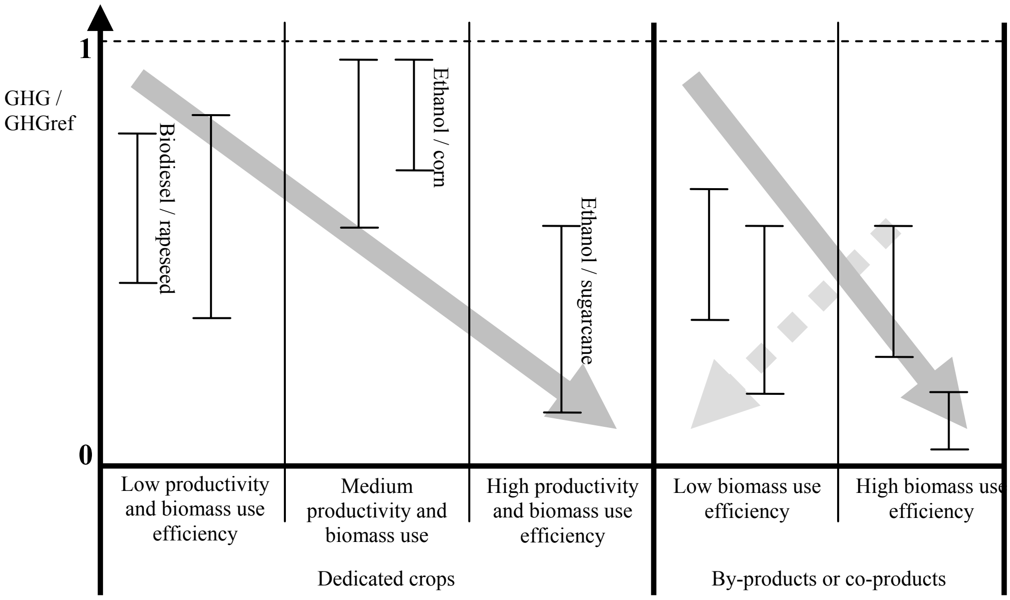

Figure 2.3 GHG effectiveness of different bioenergy systems. (B. Schlamadinger, Johanneum research, personal communication)

Note: GHG is the emission per unit of final energy for the biomass system (including all upstream energy inputs), and GHGref is the emissions from the fossil reference system (including all upstream energy inputs) that would have resulted in absence of bioenergy use. The vertical axis in the diagram indicates the productivity of land for production of final energy per hectare. The GHG balance is optimal for high productivity systems with low GHG/GHGref (grey arrow indicate this optimization).

The reviewed biomass potential studies, however, do in general not analyze the GHG reduction potential as they focus on the supply and demand of biomass. The demand-driven studies of (Obersteiner et al., 2006, Rokityanski et al., 2007) determine the economic potential of biomass using among other carbon prices. As such, they use assumptions on carbon sequestration in reforestation/afforestation activity, but do not calculate GHG balance of the whole biomass production and use chain.

2.5 Resulting data for key parameters

2.5.1 Resulting potentials

The scope in terms of biomass resources included as well as the scenario assumptions vary between the different studies. As a consequence, biomass potentials vary widely, see Figure 2.4. All of the studies presented used several scenarios. Here, the respective highest and lowest potentials of each study are shown.

The high biomass potential for 2050 determined by Smeets et al. (2007) is by far the largest potential, while the low biomass potential of Smeets et al. (2007) is within the range of several other estimates. This can be explained by the fact that Smeets et al. (2007) assumed a scenario with a very high technological level of agricultural production in order to show possible potentials that arise with an intensification of agriculture. In this scenario, converting large parts of animal production to land-less systems and using abandoned pastures for biomass production has been included; an aspect that has not been investigated in other biomass potential studies. Finally, Smeets et al. (2007) included all types of biomass resources.

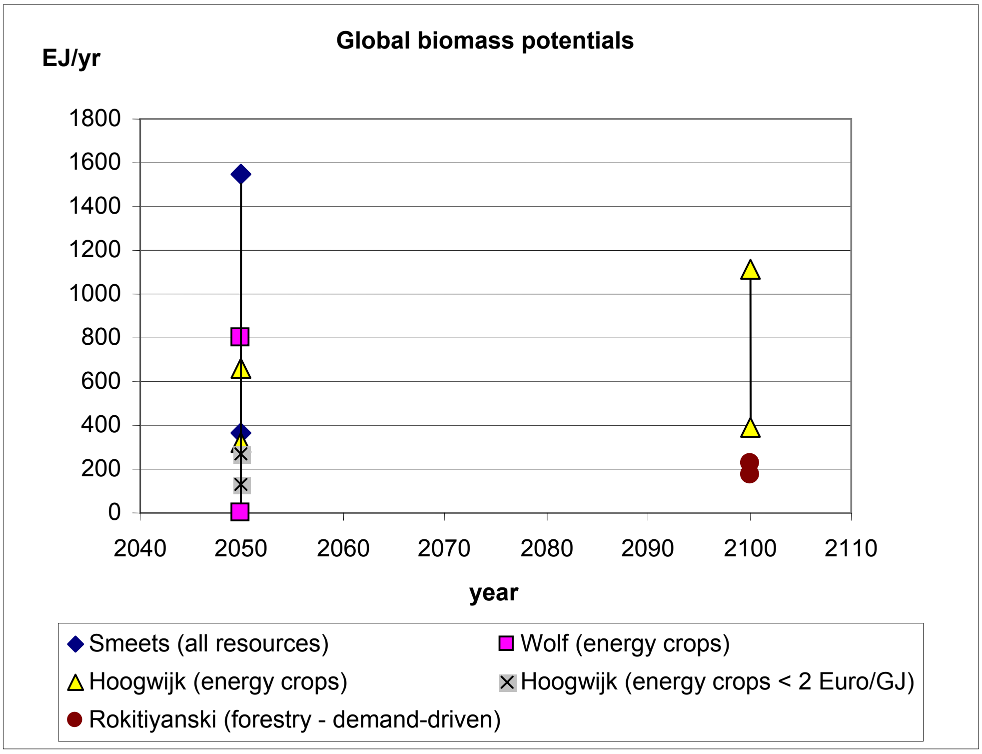

Figure 2.4 Ranges of estimated global biomass potentials (Upper and lower ranges of scenario results are presented for each study.)

On the contrary, the low biomass potential for 2050 calculated by (Wolf et al., 2003) is by far the lowest potential with about 0 EJ/yr. This is due to the fact, that the scenario assumptions are pessimistic with regard to population growth and food demand and that a low intensive ('ecological') production system has been assumed. Yields assumed for bio-energy crops are in general low, i.e. yields of grassland are assumed.

Hoogwijk et al. (2005) used an integrated assessment model and analyzed biomass potentials for the IPCC SRES scenarios. Therefore, the scenarios represent a more or less economically and ecologically developing world, but are not created to present specifically optimistic or pessimistic assumptions with regard to biomass potentials. Estimated biomass potentials for 2050 are well within the range of other estimates. For the year 2100, these biomass potentials increase especially compared to 2050 in the scenarios with high biomass potentials. The economic potential, i.e. biomass that is available for below 2 €/GJ (about the current price of coal), is lower than the technical potential in 2050. However, the economic potentials in these scenarios are still higher than the pessimistic potentials estimated by (Wolf et al., 2003).

Rokitiyanski et al. (2007) estimated the economic potential for afforestation/reforestation measures in 2100. These potentials include the establishment of short rotation forestry on agricultural land. This option is comprised under energy crops in the other studies regarded. Yields of forestry are assumed to be rather low in a low intensive management system. At the assumed carbon and energy prices that are derived from the integrated assessment model MESSAGE using the SRES scenarios, biomass potentials from afforestation/reforestation are comparably low, i.e. about 200 EJ/yr.

Summarizing, agricultural production systems and resulting crop yields as well as the availability of land for biomass production, energy prices and biomass production costs remain the main parameters determining biomass potentials. These in turn depend on local circumstances and economic mechanisms as discussed in the Section 'the ideal study'.

For comparison, the integrated assessment models MERGE, ISGM and MiniCAM estimate biomass potentials that are driven by the stabilization of greenhouse gases in the atmosphere to be rather low. Biomass potentials range between 20-150 EJ/yr in 2050 and 100-250 EJ/yr in 2100.

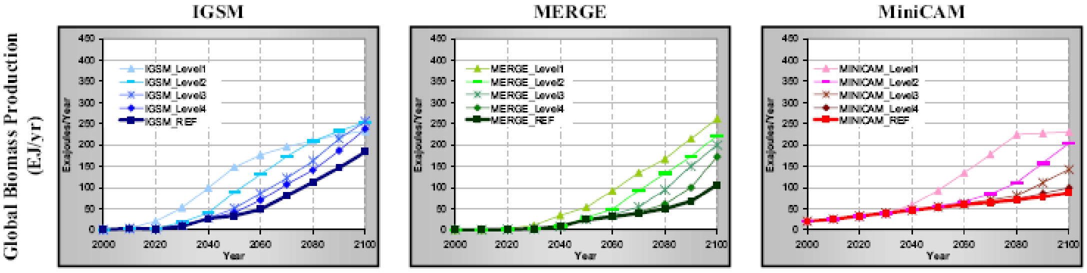

Figure 2.5 Global biomass production across scenarios (USCCSP, 2006

2.5.2 Evaluation of knowledge gaps in studies

2.5.2.1 Water

The use and availability of water has been included in the biomass potential studies in a very simplified manner, e.g. by using rain-fed yields and management factors. Technologies and amount of irrigation as well as infiltration into soils and plant-availability of water are not specified in biomass potential studies. Also, the possibility of irrigation has not been analyzed sufficiently, i.e. in which geographic areas, on which soils, technology to be used, increase of yields, amount of water used and consequences for soil and water quality have not been investigated. Also, the impact of different agricultural production systems on future water quality and availability (e.g. effects from the root system on ground water levels) has not been addressed. Finally, water demands from other uses and limitation due to water quality aspects are not taken into account and a potential competition for water resources has not been investigated.

2.5.2.2 Food demands and agricultural production

Food demands are well taken into account in most biomass potential studies. Often results on food demands are based or compared to agricultural models such as the Agricultural Economy model of IMAGE, the model used for the Agricultural Outlook of USDA, the IFPRA model or the Basic-Linked System model. These models determine food demands depending on scenario assumptions about economic growth, income and diets.

A key aspect of food demands and the resulting available biomass potentials are the use of proteins in human diets as animal products require much larger amounts of agricultural land per grain equivalent than vegetable products. Whereas, the amount of animal products varies in the different food demand projections, alternative ways to provide proteins for human consumption (new food product developments and seafood) are not considered.

Another important aspect is the intensity of agricultural production, especially in the animal production system. Smeets et al. (2007) show that much land can be released when production of meat and diary products is done in more intensive (partly land-less in closed stables) schemes. Such changes in land-use functions are so far poorly studied. Assumptions on future crop yields and learning in agricultural production systems vary widely between the biomass potential studies. A more detailed analysis based on experiences in the agricultural sector could give insight into the factors that determine future crop yields.

2.5.2.3 Material and energy demands

Most studies do not model the demand for wood products endogenously, but use demand projection from forestry sector models (e.g. UNECE, FAO). These projection, however, do not take into account the influence of an increased bioenergy demand on the forestry sector, i.e. on wood supplies and demands. The use of biomass for other materials apart from energy carriers and wood products (e.g. chemicals) has not been considered at all and requires further research.

Energy demands, i.e. amounts and prices, are important to determine the economic potential of biomass on top of the technical supply potential. However, most studies regarded here are supply-driven studies that do not take into account energy demands, while studies regarding energy demands often use a simplified description of supply; see for example (Gielen et al., 2002; Schneider and McCarl 2003). As a consequence, the influence of energy demands on the supply of biomass for energy and the use of biomass for other uses such as food and materials has been analyzed poorly. Therefore, approaches between supply- and demand-driven studies need to be merged in supply-demand driven methodologies.

2.5.2.4 Economic mechanisms

Economic mechanisms are underexposed in the biomass potential studies regarded. First, while agricultural economy models often take into account the competition between different crops based on production costs and prices, in most biomass potential studies, such economic competition between crops is not considered. Instead the availability of land depends solely on the supply of food demands. A comparison of revenues (prices minus production costs) on a locally specific level would improve knowledge about economic potentials as well as implementation potentials.

Second, demand-driven biomass potential studies compare the demand for biomass with potential supplies. However, these demand-driven energy models often use simplified assumption on biomass supplies as approaches to estimate global biomass cost-supply curves are still at the beginning. While the study of (Hoogwijk et al., 2004) provides valuable insight into cost-supply curves, production costs of biomass could be further specified and adapted to local conditions and crops.

Third, change of demand and supply of food, materials and energy as well as related changes to the demand and supply of agricultural land and forest resources due to an increased bio-energy production have not been analyzed in detail. For example, none of the selected studies takes into account varying land prices that depend directly on the demand for food and energy endogenously. Methods to include these economic mechanism into biomass potential studies that analyze biomass supplies in a detailed way—e.g. by using substitution elasticity—still need to be developed and/or adapted.

2.5.2.5 Biodiversity

The effect of producing an identified biomass potential on biodiversity and soil quality as well as the effect of a biodiversity or soil quality objective on biomass potentials, have not been clearly identified in the biomass potential studies. For example, land areas to be used, soil types, effects of different production systems, etc. are not included in current biomass potential studies. A development of more differentiated methods with regard to biodiversity and soil quality than the general approaches that have been used, e.g. exclusion of x% land or overall application of ecological production systems, seems necessary.

2.6 Conclusions

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 (Berndes et al., 2003) and in the case of economical potentials also on differences in the estimated production costs. Underlying issues under these assumptions that remain largely unresolved are (1) local conditions that determine crop yields, e.g. water availability, soil quality, agricultural production systems, learning and biodiversity aspects and (2) issues that deal with the competition between biomass production and other economic sectors, e.g. water demands from different sectors, relation between energy, food, materials and bio-energy demands and prices, and competition for land..

Recent studies on biomass potentials that have been carried out after the review of (Berndes et al. 2003) address some of these open questions. We analyzed 8 recent studies that either estimate global biomass potentials and/or that developed methodology further:

- Fischer et al. (2005) estimated crop yields for perennial crops (poplar, miscanthus and willow) based on climate and soil data on a grid-cell level for Eastern Europe and Asia, while such detailed crop yield data earlier was only available for common agricultural crops.
- Hoogwijk et al. (2005) applied an integrated assessment to biomass potential estimates. An important development in this assessment is the inclusion of land-cover and agricultural production depending on food demand and general economic developments. Also biodiversity objectives have been included in relation to land availability for biomass production.
- Hoogwijk et al. (2004) estimated global cost-supply curves for biomass based on regional and scenario-dependent data. Such cost-supply curves had not been available before.
- Obersteiner et al. (2006) included competition between agricultural uses and (short rotation) forestry uses on a grid-cell level by comparing net present values of these options.
- Perlack et al. (2005) studied biomass potential for the U.S. adding knowledge on expected learning rates in agricultural production systems (including genetic manipulation), on recoverable fractions of agriculture and forestry residues and on impacts of no-tillage systems on biomass potentials.
- Rokityanski et al. (2007) added energy and carbon prices resulting from integrated assessment of energy demands to the net present value approach of Obersteiner et al. (2006).
- Smeets et al. (2007) provides a thorough bottom-up analysis of various levels of agricultural production systems that is applied to a regional scale. Of particular importance are the analysis of animal production systems and the related possibility of the conversion of pastures to biomass production.
- Wolf et al. (2003) analyse the amount of biomass potential based on an analysis of human diets as well as agricultural food production.

Thus, recent biomass potential studies give more detailed and well-founded insights into future biomass potentials. None of the studies reviewed explicitly deals with GHG balances of biomass uses as these are part of a large body of bottom-up literature on biomass production and conversion.

It can be summarized that none of the biomass potential studies reviewed includes all critical aspects described above. Furthermore, a large part of important methodological and data issues remain unresolved in the recent studies even though often more knowledge is available in other scientific disciplines as has been shown in other part of the assessment; i.e. assessment on the knowledge base in the fields of water, food, biodiversity, energy demand and economic mechanisms. Important remaining issues are:

- 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 possible protein chains have been poorly included in the potential estimates, while the impacts of different animal production systems could be studied in more detail and applied to more biomass potential studies
- Crop yields due to different agricultural production system have a large impact on biomass potentials (Perlack et al., 2005; Smeets et al., 2007), but more knowledge on the expected rates of learning and implementation of advanced technologies in agriculture would be desirable.
- 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.

Further research on specifying yields of food crops, energy crops and forestry depending on detailed local conditions, water availability and developments of agricultural technology seems desirable. Also research on the competition between biomass for energy and materials with food, wood products and other energy carries as well as competition for water and land resources is necessary.

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3 Food demand

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3.1 Summary Food demand

3.1.1 Introduction

The key metric with regard to **food demand** is elusive. It might be hard enough to estimate either future **food production** or **food consumption**. Please note in the Netherlands the latter is about 20% lower than the former (Quist, 2000). This difference can only be approximated, since the quality of FAO **food supply** data is poor (and again different from food production, for it is defined as (production + imports - exports) per country, per commodity), and food consumption data is far from ubiquitous. Furthermore, food prices (one of the most important incentives) are hard to predict and consumer taste is capricious. Population trends seem relatively predictable, but (particularly long-term) technological trends are not. Finally, the area is thoroughly intertwined with all other areas (such as energy, water, biodiversity), adding to the complexity, which is already high in its own right. Whether defined as demand, consumption, supply or production, it is abundantly clear that crucial determinants of estimates will be 1) world population, 2) economic aspects (including income and food prices), 3) production systems, 4) diet characterisation and 5) geographic resolution and variation.

It stands to reason that food demand is a function of world population, but it is equally obvious that this is not a linear relationship. In theory, there might be something that could be called an average diet, but in actual practice nutritionally optimal diets are strongly dependent on individual requirements (since the genetic make-up of individuals varies over a huge range) and individual taste is strongly modified by economic potential, availability and cultural preferences. As a result, currently about 800 million people are malnourished and about 800 million people are obese due to excessive intake of food. In IFPRI's 2020 Vision, the International Food Policy Research Institute devotes explicit attention to the strong coupling between food demand and an increasing world population (Islam, 1995).

Due to increasing world population and affluence, certain human activities with huge environmental impacts – rather than gradual improvement – require a radical systems change, i.e. a societal transition. Recognised targets for transition include the production and consumption of food, energy and water. Notably, food production appropriates about 75% of available freshwater, 35% of land and 20% of energy. Within the food area, meat production has a disproportionate environmental impact (Aiking et al., 2006a) via both resource utilisation (land use, biodiversity, freshwater) and pollution (climate change, pesticides, eutrophication). Therefore, the impacts of food demand are strongly coupled to actual diets.

3.1.2 The ideal study

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, last but not least, 4) diet characterisation, 5) in sufficient geographic and temporal detail. In view of the complexity sketched above, such is not easy, if at all feasible.

3.1.3 Review of recent studies estimating food demand

The principal food demand projections are by the FAO. The most recent FAO projections are based on FAOSTAT data and were published in a book (Bruinsma, 2002). Concerning the focus and methods used, it is stated:

“A long-term assessment of world food, nutrition and agriculture could deal with a great number of issues, the relevance of which depends on the reader’s interest in a particular country, region or topic. As a global study, however, this report had to be selective in the issues it addresses. The main focus is on how the world will feed itself in the future and what the need to produce more food means for its natural resource base. The base year for the study is the three-year average for 1997-99 and projections are made for the years 2015 and 2030. The choice of 2015 allows assessment of whether or not the goal of the 1996 World Food Summit — to halve the number of chronically undernourished people — is likely to be reached. Extending the horizon to 2030 creates a sufficiently long period for the analysis of issues pertaining to the world’s resource base — in other words, the world’s ability to cope with further degradation of agricultural land, desertification, deforestation, global warming and water scarcity, as well as increasing demographic pressure. Naturally, the degree of uncertainty increases as the time horizon is extended, so the results envisaged for 2030 should be interpreted more cautiously than those for 2015.”

The FAO projections take freshwater resources into account, but biofuel production is not addressed. Overfishing is acknowledged, but crop demand by aquaculture is not. Further intensification of livestock production is cheered without even mentioning the concomitant risk of emerging zoonotic diseases such as avian influenza. Projections are at a general, aggregate level and quite optimistic with regard to yield increases and the effects of climate change. It is concluded that 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. In general, FAO seems to implicitly and explicitly favour further intensification of agriculture, without paying much attention to the potential of organic production. By the same token, the biorefinery concept has not yet been integrated in mainstream FAO thinking.

Notwithstanding, in a recently published report (Steinfeld et al., 2006) on the environmental impacts of livestock production, which is explicitly addressing climate change, water depletion and pollution, and biodiversity, the FAO came to the conclusion: “An important general lesson is that the livestock sector has such deep and wide-ranging environmental impacts that it should rank as one of the leading focuses for environmental policy: efforts here can produce large and multiple pay-offs. Indeed, as societies develop, it is likely that environmental considerations, along with human health issues, will become the dominant policy considerations for the sector.”

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, and from 2005 on the OECD studies were in fact performed in close cooperation with the FAO.

3.1.4 Resulting data for key parameters

Projections of the global population and GDP generally follow the WHO and World Bank scenarios, respectively. In that sense, they are the best available, but on a relatively crude geographical (national) scale. Ranges of income and, in particular, prices of food commodities are even harder to predict and strongly dependent on external, often interrelated parameters.

Primary production systems underlying FAO projections are described in sufficient detail, however, their development and future contributions to world food production seem to be severely underestimated. The direction and rate of innovation of primary production is taken into account, but evidently hard to model. The real drawback of FAO data is 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. If only post-harvest losses could be reduced substantially, and major losses that take place in households.

Last but not least, food demand strongly depends on consumer choice, i.e. in addition to affordability (price/income) and availability, cultural aspects such as status and cultural trends come into play. 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.

3.1.5 Conclusions

The principal food demand projections are by the FAO. They are the best available, but are based on supply (production + imports - exports) per country, per commodity. Even the descriptive data is crude, let alone projections based on them. The basis is not very firm 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.

The largest gap in the available models and data is probably in consumer choice. Studies of diet change show that in addition to availability and price, status aspects and cultural trends play important roles (Beardsworth and Keil, 1997; Montanari, 1994; De Boer et al., 2006). In short, prices, production, innovation and markets of all other agricultural, forestry and fisheries products exert strong influences on food demand. On top of that, there is a cultural modifier involving consumer behaviour, which is crucial, but inherently hard to predict.

Four of the biomass potential studies touched upon in chapter 2 have been reviewed with respect to the same five criteria used to evaluate food demand estimates. From a food demand perspective, the study by Hoogwijk et al. (2005) came out ahead of the rest, but in all four studies - assuming the global standard of living and the concomitant consumption of animal products keep rising - it seems likely that future food demand is underestimated and, therefore, biomass potential is overestimated.

The production of food products of animal origin, such as meat, dairy products (and even fish in aquaculture) play a key role in land and water resources appropriation by food production as a whole and, consequently, on biomass potential. To a very large extent, therefore, the demand for animal food products is likely to be the key factor determining overall food demand, and its impacts on the environment and on natural resources. Unfortunately, the demand for animal food products magnitude is inherently hard to estimate.

3.2 Introduction

3.2.1 Food consumption, food production and sustainability

Food production and consumption are clearly intertwined, if not tightly coupled. Food is important to individuals as well as to society, both providing nutrients and generating income (Tansey and Worsley, 1995). The evolution of agriculture and industry (and the technology involved) have both shaped and been shaped by world population growth (Evans, 1998). Therefore, food production and consumption, technology and society cannot be considered to be independent of one another. Due to continued growth of both world population and per capita income a major proportion of global environmental pressure is generated by food-related human activities (Bruinsma, 2002; Evans, 1998). Crops are produced, processed and turned into food products in ever larger volumes, with ever increasing impacts on the environment (Hoffmann, 2001; Millstone and Lang, 2003; Tilman et al., 2002). Currently, about one-third of all transport is food-related and, moreover, over one-third of the ice-free land area is used for food production, plus over three quarters of the available freshwater (Smil, 2002a: 239). The environmental impacts of food production include resource depletion and pollution on all scale levels from local to global. Impacts on biodiversity (Nierenberg, 2006a), climate change, and eutrophication (Postel, 2006), as well as pollution by pesticides are prominent examples, targeting environmental health as well as human health.

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). First, it should be realised that close to **half** the present world population of 6 billion would not presently be around without artificial fertilisers (Smil, 2001), which cause considerable climate change due to the high energy input required plus considerable eutrophication because they leach more easily from the soil than natural nitrogen sources (Crews and Peoples, 2004). Next, it has to be realised that during the last few decades we have been seriously depleting fish stocks (Pauly et al., 2002), thus compromising the rights of future generations. Aquaculture is unlikely to fill that gap, since a) carnivorous fish are net fish consumers and b) herbivorous fish require a primary protein source from intensive agriculture and lots of energy input. So far, technology has been able to keep up with population growth by increasing yield per hectare, but mainly by intensifying production. This has resulted in problems with human and animal health, as well as a decrease in animal welfare, as is evident from a string of recent food scares (BSE, foot-and-mouth disease, swine fever, avian influenza, dioxins, hormones, antibiotics etc.) and an upcoming obesity epidemic. Primarily due to increasing welfare, between 1970-1996 the relative proportion of people suffering from malnutrition and hunger has halved (from 37% to 18% of the world population), however, the absolute number of people afflicted has just decreased from 960 to 790 million (Bruinsma, 2002). In summary, important questions may include: to what extent are trade-offs between hunger, health, equity, sustainability and the rights of future generations allowed? Or between food and energy production, for that matter?

In order to reduce the impacts of human activities on the environment significantly, rather than some **gradual** improvement, a **stepwise** change is required (Vellinga et al., 1998; Weaver et al., 2000). This is often referred to as a societal “transition” (or, alternatively, as industrial “transformation”, stressing the technological aspects). In fact, the production of 1) food, 2) energy and 3) water have been identified as three main targets for stepwise “transition”, in stead of incremental improvement (Vellinga and Herb, 1999). Moreover, these three main activities are not independent of one another, since food production appropriates a major share of freshwater and energy produced. Due to its sheer bulk (see above), such a transition is particularly necessary in the food area (Aiking et al., 2000; Green et al., 1999).

3.2.2 Dietary aspects

Within the realm of food, meat takes a unique place for its high social status (Beardsworth and Keil, 1997). On average, 6 kg of plant protein is required to yield 1 kg of meat protein (Pimentel and Pimentel, 2003; Smil, 2000). Due to this inherently inefficient conversion, meat is responsible for a disproportionate share of environmental pressure (Bradford, 1999; Brown, 1996; Delgado et al., 1999; Gilland, 2002). While the world population doubled during the second half of the 20th century, its appetite for meat quadrupled, requiring 40-50% of the world grain harvest to be fed to livestock (Evans, 1998). When striving for sustainable ways of food production and consumption, therefore, the protein chain is an excellent starting point (Grigg, 1995; Millstone and Lang, 2003; Smil, 2002b). 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. Several economic arguments (Seidl, 2000; White, 2000) indicate, however, that actual practice may be not as straightforward as theory suggests. Building on a preceding desk study on sustainable technology development (Weaver et al., 2000), the multidisciplinary (political, social, economic, technological, environmental, ecological, and chemical) PROFETAS programme (Protein Foods, Environment, Technology And Society) was devised (Aiking et al., 2000).

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 freshwater to start with. Moreover, world wide there is potential for a 30-40 fold reduction in water use. The same beneficial factor holds for acidification. The geographic location of these and other environmental benefits will, however, depend very much on the actual selection of crops to be used as raw materials. Crop growth modelling applied to pea growth suggested that in the EU with low resource input high pea crop yields may be **anticipated** in Scandinavia (in addition to **current** production in France and the UK). The same model can be used for other protein crops, thus revealing optimal geographic locations for sustainable protein production (Aiking et al., 2006b). A study on protein crop options shows that, in Europe, potential raw materials might include lupin, pea, quinoa, triticale, lucerne, grasses, rapeseed/canola and potato, and that outside Europe at least soy should be added. However, the feasibility to be a suitable source for NPFs was shown to be an insufficient condition. Since just 20-40% of the seeds is protein, extra waste from the non-protein fraction (up to 80% of the crop) would largely offset the potential 4-6 fold environmental gain from replacing indirect (meat) with direct plant protein consumption. Therefore, useful application of the non-protein fraction is indispensable to a protein transition, and should influence crop selection. At present, therefore, oil crops (such as soy or rapeseed) seem preferable over starchy crops (such as pea) with regard to biofuel production. In this respect, it is evident that combining sustainable production of protein and energy in one crop will simultaneously mitigate agricultural resource depletion, agricultural pollution, as well as climate change: a clear case of win-win-win (Aiking et al., 2006a). In fact, combustion of dedicated energy crops may be considered a waste of valuable protein which is burnt.

3.2.3 Socio-economic aspects

To make food production more sustainable, a stepwise improvement is required, a so-called transition (Green et al., 1999; Weaver et al., 2000). In the past many food transitions have taken place (Grigg, 1995), but they always evolved passively, as products of a multitude of chance factors. In particular a transition from animal to plant protein would be highly beneficial to the environment, due to the inherently inefficient conversion step from plant protein to animal protein (Smil, 2000). It is currently thought in The Netherlands that active transition “management” should be sought by the government (Kemp and Loorbach, 2003). However, many actors are involved, all of which will perceive their own barriers and opportunities. In PROFETAS (Aiking et al., 2006a), at least four barriers to such a transition towards decoupling protein production from concomitant environmental impacts have been identified: 1) social forces opposing change are strong, because meat has a high status, 2) economic forces opposing change are strong, because established interests in the meat chain are powerful, 3) technological know-how on novel (plant) protein foods is lacking, and 4) for centuries the meat chain has been optimised for exhaustive use of all by-products, potentially offsetting a large part of the theoretical environmental gain. The latter, in particular, complicates matters by the concomitant allocation issues.

Relevant actors include consumers, retailers, food processors, farmers, NGOs and policymakers from government and industry, both nationally and internationally, including GATT and its repercussions (ESC, 2002). Interestingly, opportunities and obstacles for a transition turn out to be strongly different depending on the level (from local to global). In Asia, for example, incentives, crops and consumer taste are different from Europe. Therefore, regional approaches to a protein transition are called for. From an environmental point of view, there is no doubt that Novel Protein Foods are environmentally more friendly than meat. But the real environmental benefits of NPFs depend on their acceptance by the consumers (Aiking et al., 2006a). Even in developed countries, only a minority of the consumers is prepared to avoid meat and if they do, **health issues** are much stronger incentives than **environmental issues** (Beardsworth and Bryman, 2004). In contrast, in developing countries, in particular, the proportion of meat in the diet is rising rapidly (Bruinsma, 2002). Economic analysis indicates that if only the “rich” consumers switch to consume more NPFs to partly replace meat, the meat production and emissions will hardly be reduced because of increasing demand of meat of “low income” and “middle income” consumers in developing countries (Zhu, 2004) with a concomitant effect on cereals consumption (Keyzer et al., 2005). The GTAP economic model predicted meat prices to continue decreasing, however, the GEMAT model predicted a reversing trend (Van Wesenbeeck and Herok, 2006). Although sustainability is a global issue, European researchers will experience difficulty enough trying to grasp what’s on the minds of European consumers (Verbeke, 1999), and could not possibly dream of modelling the non-

European consumer with any degree of accuracy. Nevertheless, a trend setting Western diet change might have an impact world wide.

3.3 Parameters crucial to food demand

3.3.1 Complexity

The key metric in this area has to be determined yet. Originally phrased as **food demand**, it might be hard enough to estimate future **food production** or **food consumption**. Please note the latter is about 20% lower (Quist, 2000). This difference can only be approximated, since the quality of FAO **food supply** data is poor (and again different from food production) and food consumption data is far from ubiquitous. Furthermore, food prices (one of the most important incentives) are hard to predict and consumer taste is capricious. Population trends seem relatively predictable, but (particularly long-term) technological trends are not. Finally, the area is thoroughly intertwined with all other areas, adding to the complexity, which is already high in its own right. From the preceding section it becomes abundantly clear that whether defined as demand, consumption, supply or production, crucial determinants of estimates will be 1) world population, 2) diet characterisation, 3) production systems, 4) economic aspects (including income and food prices) and 5) geographic resolution and variation. These will be dealt with in the following sections.

3.3.2 World population

It stands to reason that food demand is a function of world population, but it is equally obvious that this is not a linear relationship. In theory, there might be something that could be called an average diet, but in actual practice nutritionally optimal diets are strongly dependent on individual requirements (since the genetic make-up of individuals varies over a huge range) and individual taste is heavily modified by cultural preferences, availability and economic potential. As a result, currently about 800 million people are malnourished and about 800 million people are obese due to excessive intake of food.

In IFPRI's 2020 Vision, the International Food Policy Research Institute (see subsequent sections also) devotes explicit attention to the strong coupling between food demand and an increasing world population (Islam, 1995).

3.3.3 Diet characterisation

Both nutritionally and environmentally, the most important diet constituents are carbohydrates and proteins, for reasons touched upon in preceding sections. Healthwise, fats may come next, but when trying to estimate food demand they are less important. Quantitatively, in fact, proteins may also seem secondary to bulk carbohydrates. The environmental impacts of protein consumption and production are so overwhelming, however, that any estimation of food demand should at least take protein into consideration, specifying the anticipated consumption of proteins and their origins, such as the type of plant protein crops, the type of seafood, the type of animal proteins, including milk products, eggs, and meats (De Boer et al., 2006). Furthermore, it should be kept in mind that malnourishment is often a case of insufficient proteins, rather than a case of insufficient calories.

In a recent report (Steinfeld et al., 2006), addressing the impacts of livestock production on climate change, water depletion and pollution, and biodiversity, the FAO stated: “The livestock sector is by far the single largest anthropogenic user of land. The total area occupied by grazing is equivalent to 26 percent of the ice-free terrestrial surface of the planet. In addition, the total area dedicated to feedcrop production amounts to 33 percent of total arable land. In all, livestock production accounts for 70 percent of all agricultural land and 30 percent of the land surface of the planet. Expansion of livestock production is a key factor in deforestation, especially in Latin America where the greatest amount of deforestation is occurring - 70 percent of previous forested land in the Amazon is occupied by pastures, and feedcrops cover a large part of the remainder."

3.3.4 Production systems

On the supply side there is a myriad of production systems. Although crops are different from one country to the next, it should be realised that, maybe even more importantly, the same crop may give entirely different yields, depending on local circumstances, both physical and cultural. Obviously, the latter include soil and climate parameters, but also agricultural practices such as tilling, application of pesticides, fertiliser and irrigation (by means of many different systems). An extremely important aspect is the regime of intercropping and rotation of crops. The huge variety of parameters involved and their huge ranges have resulted in a virtual absence of a global overview beyond an inventory of existing farming systems. Projections of food supply are, therefore, available exclusively on the aggregate level of some major crops or commodities, such as certain types of cereals and meats, but lacking on a more detailed level. For the former, see (Smil, 2000) for example. Below, farming systems in the developing world will be detailed according to a joint FAO/World Bank report (Dixon et al., 2001), providing the most exhaustive inventory to date.

The FAO/World Bank report (Dixon et al., 2001), though acknowledging that actual reality is considerably more heterogeneous, classified farming systems based on a number of key factors, including: (i) the available natural resource base; (ii) the dominant pattern of farm activities and household livelihoods, including relationship to markets; and (iii) the intensity of production activities. These criteria were applied to each of the **six main regions of the developing world**. The exercise resulted in the identification of 72 farming systems with an average agricultural population of about 40 million inhabitants. Based on these criteria, eight broad categories of farming system have been distinguished:

- Irrigated farming systems, embracing a broad range of food and cash crop production;
- Wetland rice based farming systems, dependent upon seasonal rains supplemented by irrigation;
- Rainfed farming systems in humid areas, characterized by specific dominant crops or mixed crop-livestock systems;
- Rainfed farming systems in steep and highland areas, which are often mixed crop-livestock systems;
- Rainfed farming systems in dry or cold low potential areas, with mixed crop-livestock and pastoral systems merging into systems with very low current productivity or potential because of extreme aridity or cold;
- Dualistic (mixed large commercial and small holders) farming systems, across a variety of ecologies and with diverse production patterns;
- Coastal artisanal fishing systems, which often incorporate mixed farming elements; and
- Urban based farming systems, typically focused on horticultural and livestock production.

Except for the dualistic systems, the systems within each category are dominated by smallholder agriculture. The names chosen for individual farming systems reflect the eight categories outlined above. They also reflect key distinguishing attributes, notably: (i) water resource availability, e.g. irrigated, rainfed, moist, dry; (ii) climate, e.g. tropical, temperate, cold; (iii) landscape relief/altitude, e.g. highland, lowland; (iv) farm size, e.g. large scale; (v) production intensity, e.g. intensive, extensive, sparse; (vi) dominant livelihood source, e.g. root crop, maize, tree crop, artisanal fishing, pastoral; (vii) dual crop livelihoods, e.g. cereal-root, rice-wheat (note that crop-livestock integration is denoted by the term mixed); and (viii) location, e.g. forest based, coastal, urban based.

Table 3.1 Major farming systems of sub-Saharan Africa (Dixon et al., 2001).

Farming systems	Land area (% of region)	Agricultural population (% of region)	Principal livelihoods
Irrigated	1	2	Rice, cotton, vegetables, rainfed crops, cattle, poultry
Tree crop	3	6	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work
Forest based	11	7	Cassava, maize, beans, cocoyams
Rice-Tree crop	1	2	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work
Highland perennial	1	8	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work
Highland temperate mixed	2	7	Wheat barley, tef, peas, lentils, broadbeans, rape, potatoes, sheep, goats, livestock, poultry, off-farm work
Root crop	11	11	Yams, cassava, legumes, off-farm work
Cereal-Root crop mixed	13	15	Maize, sorghum, millet, cassava, yams, legumes, cattle
Maize mixed	10	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work
Large commercial and smallholder	5	4	Maize, pulses, sunflower, cattle, sheep, goats, remittances
Agro-pastoral millet/sorghum	8	8	Sorghum, pearl millet, pulses, sesame, cattle, sheep, goats, poultry, off-farm work
Pastoral	14	7	Cattle, camels, sheep, goats, remittances
Sparse (arid)	17	1	Irrigated maize, vegetables, date palms, cattle, off-farm work
Coastal artisanal fishing	2	3	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work
Urban based	<1	3	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work

It was concluded that the overall challenge to reduce hunger and poverty in sub-Saharan Africa is in 5 strategic interlinked initiatives:

- Sustainable resource management;
- Improved resource access;
- Increased small farm competitiveness;
- Reduced household vulnerability; and
- Responding to HIV/AIDS.

Table 3.2 Major farming systems of Middle East and North Africa (Dixon et al., 2001).

Farming systems	Land area (% of region)	Agricultural population (% of region)	Principal livelihoods
Irrigated	2	17	Fruits, vegetables, cash crops
Highland mixed	7	30	Cereals, legumes, sheep, off-farm work
Rainfed mixed	2	18	Tree crops, cereals, legumes, off-farm work
Dryland mixed	4	14	Cereals, sheep, off-farm work
Pastoral	23	9	Sheep, goats, barley, off-farm work
Sparse (arid)	62	5	Camels, sheep, off-farm work
Coastal artisanal fishing	1	1	Fishing, off-farm work
Urban based	<1	6	Horticulture, poultry, off-farm work

Five broad strategic initiatives are proposed:

- Sustainable resource management;
- Improved irrigation management;
- Reoriented agricultural services;
- Revitalised agricultural education systems; and
- Rationalised agricultural policies.

Table 3.3 Major farming systems of Eastern Europe and Central Asia (Dixon et al., 2001).

Farming systems	Land area (% of region)	Agricultural population (% of region)	Principal livelihoods
Irrigated	1	4	Cotton, rice, other cereals, tobacco, fruit, vegetables, off-farm
Mixed	4	18	Wheat, maize, oil crops, barley, livestock
Forest based livestock	3	5	Fodder, hay, cereals, industrial crops, potatoes
Horticulture mixed	3	11	Wheat, maize, oil crops, fruit, intensive vegetables, livestock, off-farm income
Large-scale cereal-vegetable	4	16	Wheat, barley, maize, sunflower, sugar beet, vegetables
Small-scale cereal-livestock	1	4	Wheat, barley, sheep and goats
Extensive cereal-livestock	18	15	Wheat, hay, fodder, cattle, sheep
Pastoral	3	10	Sheep, cattle, cereals, fodder crops, potatoes
Sparse (cold)	52	2	Rye, oats, reindeer, potatoes, pigs, forestry
Sparse (arid)	6	8	Barley, sheep
Urban based	<1	7	Vegetables, poultry, pigs

The proposed interlinked initiatives are:

- Improved resource access;
- Expanded market development; and
- Reoriented and strengthened.

Table 3.4 Major farming systems of South Asia (Dixon et al., 2001).

Farming systems	Land area (% of region)	Agricultural population (% of region)	Principal livelihoods
Rice	7	17	Wetland rice (both seasons), vegetables, legumes, off-farm activities
Coastal artisanal fishing	1	2	Fishing, coconuts, rice, legumes, livestock
Rice-Wheat	19	33	Irrigated rice, wheat, vegetables, livestock including dairy, off-farm activities
Highland mixed	12	7	Cereals, livestock, horticulture, seasonal migration
Rainfed mixed	29	30	Cereals, legumes, fodder crops, livestock, off-farm activities
Dry rainfed	4	4	Coarse cereals, irrigated cereals, legumes, off-farm activities
Pastoral	11	3	Livestock, irrigated cropping, migration
Sparse (arid)	11	1	Livestock where seasonal moisture permits
Sparse (mountain)	7	<1	Summer grazing of livestock
Tree crop	dispersed	1	Export or agro-industrial crops, cereals, wage labour
Urban based	<1	1	Horticulture, dairying, poultry, other activities

Four broad interlinked strategic initiatives are proposed:

- Improved water resource management;
- Strengthened resource user groups;
- Improved rural infrastructure; and
- Reoriented agricultural services.

Table 3.5 Major farming systems of East Asia and Pacific (Dixon et al., 2001).

Farming systems	Land area (% of region)	Agricultural population (% of region)	Principal livelihoods
Lowland rice	12	42	Rice, maize, pulses, sugarcane, oil seeds, vegetables, livestock, aquaculture
Tree crop mixed	5	3	Rubber, oil palm, coconut, coffee, tea, cocoa, spices, rice, livestock
Root-Tuber	2	<1	Root crops (yam, taro, sweet potato), vegetables, fruits, livestock (pigs and cattle)
Upland intensive mixed	19	27	Rice, pulses, maize, sugarcane, oil seeds, fruits, vegetables, livestock
Highland extensive mixed	5	4	Upland rice, pulses, maize, oil seeds, fruits, forest products, livestock
Temperate mixed	6	14	Wheat, maize, pulses, oil crops, livestock
Pastoral	20	4	Livestock with irrigated crops in local suitable areas
Sparse (forest)	10	1	Hunting, gathering
Sparse (arid)	20	2	Local grazing where water available
Coastal artisanal fishing	1	2	Fishing, coconut, mixed cropping
Urban based	<1	1	Horticulture, livestock, off-farm income

Four broad interlinked strategic initiatives are proposed:
- Increased small farm competitiveness;
- Improved resource access;
- Enabling environment for the creation of off-farm income; and
- Enhanced human resource development.

Table 3.6 Major farming systems of Latin America and the Caribbean (Dixon et al., 2001).

Farming systems	Land area (% of region)	Agricultural population (% of region)	Principal livelihoods
Irrigated	10	9	Horticulture, fruit, cattle
Forest based	30	9	Subsistence production // cattle ranching
Coastal plantation and mixed	9	17	Export crops // tree crops, fishing, tubers, tourism
Intensive mixed	4	8	Coffee, horticulture, fruit, off-farm work
Cereal-livestock (Campos)	5	6	Rice, livestock
Moist temperate mixed-forest	2	1	Livestock, cereals, forestry, tourism
Maize-Beans (Mesoamerican)	3	10	Maize, beans, coffee, horticulture, off-farm work
Intensive highlands mixed (Northern Andes)	2	3	Vegetables, maize, coffee, cattle // pigs, cereals, potatoes, off-farm work
Extensive mixed (Cerrados & Llanos)	11	9	Livestock, oilseeds, grains, some coffee
Temperate mixed (Pampas)	5	6	Livestock, wheat, soybean
Dryland mixed	6	9	Livestock, maize, cassava, wage labour, seasonal migration
Extensive dryland mixed (Gran Chaco)	3	2	Livestock, cotton, subsistence crops
High altitude mixed (Central Andes)	6	7	Tubers, sheep, grains, llamas, vegetables, off-farm work
Pastoral	3	1	Sheep, cattle
Sparse (forest)	1	<1	Livestock, forestry, tourism
Urban based	<1	3	Horticulture, dairy, poultry

Note: // - within the livelihoods column separates distinguishable subsystems.

Three broad interlinked regional initiatives are proposed:
- Sustainable resource management;
- Improved resource access; and
- Increased small farm competitiveness.

The 72 farming systems identified in the six developing regions can be grouped into eight major categories, based on the characteristics described above, in order to facilitate comparison and integration of development lessons into an overall global strategy for poverty reduction.

Table 3.7 Comparison of farming systems by category (Dixon et al., 2001).

Category characteristic	Smallholder irrigated schemes	Wetland rice based	Rainfed humid	Rainfed highland	Rainfed dry/cold	Dualistic (large / small)	Coastal artisanal fishing	Urban based
Number of systems	3	3	11	10	19	16	4	6
Total land (10^6 ha)	219	330	2013	842	3478	3116	70	n.a.
Cultivated area (10^6 ha)	15	155	160	150	231	414	11	n.a.
Cultivated / Total (%)	7	47	8	18	7	13	16	n.a.
Irrigated area (10^6 ha)	15	90	17	30	41	36	2	n.a.
Irrigated / Cultivated (%)	99	58	11	20	18	9	19	n.a.
Agricultural population (10^6)	30	860	400	520	490	190	60	40
Agricultural persons / Cultivated ha	2.1	5.5	2.5	3.5	2.1	0.4	5.5	n.a.
Market surplus	high	medium	medium	low	low	medium	high	high

It is concluded that the principal farm household strategies for escaping from hunger and poverty are:

- intensification of existing patterns of farm production;
- diversification of production, including the development of market-oriented production and increased value added post-harvest activities such as processing;
- increased operated farm or herd size, either through consolidation of existing holdings or the extension of farming onto new agricultural land;
- increased off-farm income to supplement farming activities; and
- exit from agriculture, often involving migration to urban areas.

These trends are to be watched closely, since the authors conclude: “Probably the most important message that can be drawn from this study is the great potential for reducing both hunger and poverty that resides in the improvement of smallholder farming systems.” We will return to this conclusion later.

3.3.5 Economic aspects

Economic aspects are at least twofold. First of all, developing countries, in particular, generally derive a large proportion of their income from exports of agricultural products (Tansey and Worsley, 1995). Therefore, large-scale transitions in demand of food or feed (say, protein crops), or non-food agricultural products (say, materials or biofuels) will have reverberating impacts world wide. Secondly, income is an important determinant of food consumption, particularly of the more expensive animal protein foods, which displays a sigmoid, rather than a linear relationship (Keyzer et al., 2005). This means that over a minimum annual income of $2,200 (corresponding to 16.6 kg meat per year) the demand for meat will explode and over a maximum of $9,700 (77.1 kg/year) it will level off. This explosion of meat demand is exactly what is currently seen in countries such as China (Flavin and Gardner, 2006; Nierenberg, 2006a). Even in India consumers tend to drift away from vegetarianism as they become richer (Keyzer et al., 2005). As a result of booming economies, world market prices of soy and feed maize started to soar in 2006 and prices of meat are expected to follow.

3.3.6 Geographic resolution and variation

When estimating food demand, it is insufficient to produce a global average, since the geographic location (soil type, meteorological conditions, etc.) determines both the local environmental impacts and the required transport to the place of consumption (food miles). Low-resolution estimates may have an edge on global averages (Slager et al., 1994), but ideally estimates should have sufficient detail to chart the effects of organic and other relatively small-scale production systems. And then there is temporal variation, which is generally not accounted for.

3.4 Analysis of food demand estimates

3.4.1 Introduction

As indicated above, estimating food demand is particularly difficult for a number of reasons. Therefore, projections are few and rare. Generally, the efforts stop at keeping track of annual agricultural production or supply (= production + imports - exports) per country, per commodity. Such is already a formidable task and just a few international organisations are up to it, such as the FAO of the United Nations. Regularly, but infrequently, projections are made and reported (Alexandratos, 1995; Bruinsma, 2002). The latter will be described in the next section.

Other projections, such as by the OECD, focus on consumption, production and trade in OECD countries and from an economic perspective, primarily, displaying a heavy bias towards markets and policies. One of their - indeed - annual projections of agricultural production and consumption has been published as (OECD, 2004a). In addition, the OECD published a report on the relationship between biomass and agriculture (OECD, 2004b).

Finally, several reports and books are devoted to a kind of reverse projection, i.e. the maximum number of people that may be sustainably fed by planet Earth. Though there seems to be a kind of consensus approaching a global population of 10 billion (WRR, 1994; WRR, 1995; Evans, 1998), some are more cautious (Smil, 2000).

In an early attempt, the World Bank (Crosson and Anderson, 1992) developed a **scenario** for the growth of global grain demand between 1988 and 2030, treating the **demand for grains** as a proxy for the **total demand for food**. The scenario was based on the UN population projections from 1990-2030, on assumptions about the rate of per capita income growth and income elasticities of demand for grain in the developing countries, and on the assumption that, in the developed countries, demand for grain would grown only with population (zero elasticity). Most importantly, the scenario explicitly assumed the overwhelming share of the growth in global grain demand would be for food, not for other uses such as a feedstock for energy production. This watershed between the food world and the energy world remains to this day.

3.4.2 FAO

The most recent FAO projections are based on FAOSTAT data and were published in a book (Bruinsma, 2002). Concerning the focus and methods used, it is stated:
“A long-term assessment of world food, nutrition and agriculture could deal with a great number of issues, the relevance of which depends on the reader’s interest in a particular country, region or topic. As a global study, however, this report had to be selective in the issues it addresses. The main focus is on how the world will feed itself in the future and what the need to produce more food means for its natural resource base. The base year for the study is the three-year average for 1997-99 and projections are made for the years 2015 and 2030. The choice of 2015 allows assessment of whether or not the goal of the 1996 World Food Summit — to halve the number of chronically undernourished people — is likely to be reached. Extending the horizon to 2030 creates a sufficiently long period for the analysis of issues pertaining to the world’s

resource base — in other words, the world's ability to cope with further degradation of agricultural land, desertification, deforestation, global warming and water scarcity, as well as increasing demographic pressure. Naturally, the degree of uncertainty increases as the time horizon is extended, so the results envisaged for 2030 should be interpreted more cautiously than those for 2015.

The analysis is, inter alia, based on the long-term developments expected by other organizations. The population projections, for instance, reflect the latest assessment (2000 Assessment, Medium Variant) available from the United Nations (UN, 2001), while those for incomes are largely based on the latest projections of gross domestic product (GDP) from the World Bank. Most of the agricultural data are from FAO's database (FAOSTAT), as in July 2001. Because these assumptions critically shape the projected outcomes, it is important to note that they can change significantly, even over the short term. For example, the historical data and the projections for the growth of population and GDP used in the 1995 study have since been revised in many countries, often to a significant extent. World population in the 1995 study, for instance, was projected at 7.2 billion for 2010, whereas the current UN projections peg the figure at 6.8 billion. Similarly, it is now assumed that sub-Saharan Africa's population will reach 780 million by 2010, compared with 915 million in the 1995 study. The GDP projections for sub-Saharan Africa also differ from those assumed in the 1995 study: per capita income growth over the period 1997-99 to 2015 is now projected at 1.8 percent a year, compared with 0.7 percent in the 1995 study (over the period 1988-90 to 2010). Finally, FAO's historical data for food production, demand and per capita consumption were often drastically revised for the entire time series as more up-to-date information became available.

This report begins by presenting the expected developments in world agricultural demand, production and trade (both in total and by major commodity group), and the implications for food security and undernourishment. It continues with a discussion of the main issues raised by these developments. These include the role of agriculture in rural development, poverty alleviation and overall economic growth, and the effects of globalization and freer trade. The report then discusses production and policy issues in the crop, livestock, forestry and fisheries sectors, including natural resource use and agricultural technology issues. It concludes with an assessment of the environmental implications of agricultural production, including its interactions with climate change."

It should be noted here that in the 5-7 years between the first and second set of projections considerable adjustments had to be made, as described above. After this short period of time, world population was projected 6% lower, sub-Saharan population 15% lower, but sub-Saharan GDP was projected 160% higher.

In the following tables, derived from the summary report (Bruinsma, 2002), an overview of the FAO projections is given.

Table 3.8 An overview of the FAO projections (Bruinsma, 2002).

Population (millions)	**1979-81**	**1997-99**	**2015**	**2030**	**2050**
World	4430	5900	7207	8270	9322
Developing countries	3259	4595	5858	6910	7987
Industrial countries	789	892	951	979	986
Transition countries	382	413	398	381	349

Population growth (% per annum)	**1979 to 1999**	**1989 to 1999**	**1997-99 to 2015**	**2015 to 2030**	**2030 to 2050**
World	1.6	1.5	1.2	0.9	0.6
Developing countries	1.9	1.7	1.4	1.1	0.7
Industrial countries	0.7	0.7	0.4	0.2	0.0
Transition countries	0.5	0.1	-0.2	-0.3	-0.4

GDP growth (% per annum)	**1997-99 to 2015 total**	**2015 to 2030 total**		**1997-99 to 2015 per capita**	**2015 to 2030 per capita**
World	3.5	3.8		2.3	2.9
Developing countries	5.1	5.5		3.7	4.4
Industrial countries	3.0	3.0		2.6	2.8
Transition countries	3.7	4.0		4.0	4.3

Growth in demand for agricultural products (% per annum)	**1969 to 1999**	**1979 to 1999**	**1989 to 1999**	**1997-99 to 2015**	**2015 to 2030**
World	2.2	2.1	2.0	1.6	1.4
Developing countries	3.7	3.7	4.0	2.2	1.7
Industrial countries	1.1	1.0	1.0	0.7	0.6
Transition countries	-0.2	-1.7	-4.4	0.5	0.4

Growth in agricultural production (% per annum)	**1969 to 1999**	**1979 to 1999**	**1989 to 1999**	**1997-99 to 2015**	**2015 to 2030**
World	2.2	2.1	2.0	1.6	1.3
Developing countries	3.5	3.7	3.9	2.0	1.7
Industrial countries	1.3	1.0	1.4	0.8	0.6
Transition countries	-0.4	-1.7	-4.7	0.6	0.6

Calorie consumption (kcal/capita/day)	**1961-63**	**1979-81**	**1997-99**	**2015**	**2030**
World	2283	2552	2803	2940	3050
Developing countries	1960	2312	2681	2850	2980
Industrial countries	2891	3135	3380	3440	3500
Transition countries	3154	3389	2906	3060	3180

Undernourishment	**Million people**				**% of population**			
	1990-92	**1997-99**	**2015**	**2030**	**1990-92**	**1997-99**	**2015**	**2030**
World		815				14		
Developing countries	816	777	610	443	20	17	11	6
Industrial countries		11				1		
Transition countries		27				6		

Cereals	**Million tonnes**				**% per annum**			
	1979-81	**1997-99**	**2015**	**2030**	**1979 to 1999**	**1989 to 1999**	**1997-99 to 2015**	**2015 to 2030**
World								
Production	1442	1889	2387	2838	1.4	1.0	1.4	1.2
Food	706	1003	1227	1406	1.9	1.4	1.2	0.9
Feed	575	657	911	1148	0.6	0.6	1.9	1.5
Developing countries								
Production	649	1026	1354	1652	2.5	2.1	1.6	1.3
Food	524	790	1007	1185	2.2	1.7	1.4	1.1
Feed	113	222	397	573	3.8	4.4	3.5	2.5
Net trade	-66	-103	-190	-265				

Meat	**Million tonnes**				**% per annum**			
	1979-81	**1997-99**	**2015**	**2030**	**1979 to 1999**	**1989 to 1999**	**1997-99 to 2015**	**2015 to 2030**
World								
Production	132	218	300	376	2.8	2.7	1.9	1.5
Food	130	214	297	373	2.8	2.7	1.9	1.5
Developing countries								
Production	45	116	181	247	5.5	5.9	2.7	2.1
Food	44	116	184	252	5.6	6.1	2.7	2.1
Net trade	-0.2	-1.2	-3.9	-5.9				

Vegetable oils and oil seeds (oil equivalent)	**Million tonnes**				**% per annum**			
	1979-81	**1997-99**	**2015**	**2030**	**1979 to 1999**	**1989 to 1999**	**1997-99 to 2015**	**2015 to 2030**
World								
Production	50	104	157	217	4.1	4.3	2.5	2.2
Food	37	67	98	130	3.3	2.8	2.3	1.9
Industrial use	8	23	45	71	6.1	6.9	3.9	3.1
Developing countries								
Production	29	68	109	156	5.0	4.7	2.8	2.4
Food	21	45	73	102	4.3	3.6	2.9	2.2
Industrial use	3	13	26	41	8.2	10.2	4.4	3.1
Net trade	1.5	4.0	3.4	3.5				

Arable land (million ha)	**Total**				**Irrigated**			
	1997-99	**2015**	**2030**		**1979-81**	**1997-99**	**2015**	**2030**
World	1608				210	271		
Developing countries	956	1017	1076		151	202	221	242
Industrial countries	387				37	42		
Transition countries	265				22	25		

Crop land and yields in developing countries	**Harvested land (million ha)**				**Yield (tonnes/ha)**			
	1979-81	**1997-99**	**2015**	**2030**	**1979-81**	**1997-99**	**2015**	**2030**
Wheat	96	111	113	118	1.6	2.5	3.1	3.5
Rice (paddy)	138	157	162	164	2.7	3.6	4.2	4.7
Maize	76	97	118	136	2.0	2.8	3.4	4.0
All cereals	408	465	497	528	1.9	2.6	3.2	3.6
% of total	60	55	53	51				

Here, it has to be repeated that in the tables above, the word “consumption” is misleading. It simply denotes the amount disappearing from the statistics by any means, including harvest and post harvest losses - estimated at 15% for cereals (Smil, 2000; Smil, 2003) - and household losses. They add up to about 20% (Quist, 2000) in the Netherlands. The gap between food availability and actual need is estimated at 25% in China, even higher in western countries and still growing, leading to obesity and even more waste (Smil, 2003).

In summary, the FAO projections address world population growth, diet changes (to include more animal products), yield increases (including by GM) and economic aspects. Geographic resolution is crude. In general, the projections are quite - if not overly - optimistic. Freshwater resources are taken into account, but biofuel production is not. Overfishing is acknowledged, but crop demand by aquaculture is not. Further intensification of livestock production is cheered without mentioning the concomitant risk of emerging zoonotic diseases such as avian influenza.

3.4.3 OECD

Relatively recently, the OECD published an annual projection of agricultural production (OECD, 2004a). Concerning the focus and methods used, its foreword states:
“The OECD Agricultural Outlook provides a medium term assessment of future trends and prospects in the major agricultural commodity markets of OECD countries. The report is published annually, as part of a continuing effort to promote informed discussion of emerging

policy issues. This tenth edition of the OECD Agricultural Outlook, 2004-2013 is set against the background of a world economy that is on the path to economic recovery, and where OECD agricultural policy is being influenced by changes taking place in the European Union with the 2003 reform of the CAP and enlargement of the Union as well as the multi-year provisions of the US Farm Act of 2002. The Outlook for agricultural markets is for a gradual strengthening in market conditions for all commodities over the period to 2013. Stronger global economic growth is expected to lead to increased consumption and trade and firmer agricultural product prices in nominal terms. But these outcomes are highly conditional on the geopolitical and global economic situation, as well as a continuation of domestic policies and policy settings, particularly in OECD countries. A restart of the stalled Doha round of multilateral trade discussions in the WTO and their successful conclusion in terms of further trade reform, would strengthen the prospects for agricultural markets beyond that contained in this assessment which is based on only a continuation of existing policy reforms and URAA commitments.

The projections to 2013, presented in the Outlook, constitute a plausible medium-term future for the markets of key commodities. They are the result of close co-operation between the OECD Secretariat and experts in member countries, and some national co-operators in non-member economies (NMES), and hence, reflect their combined knowledge and expertise. This year's report takes account of the enlargement of the European Union, from fifteen to twenty-five countries, from 2004. The commodity projections are based on a number of assumptions relating to current or announced agricultural and trade policies in OECD countries, the outcome of the URAA multilateral trade negotiations in the WTO, the underlying macro-economic environment and its expected evolution, as well as developments in major NMEs. The OECD's Aglink model is used to guarantee internal consistency in the projections. In addition, the model is employed to generate scenarios around the Outlook baseline so that sources of uncertainty in relation to key assumptions and selected policy issues can be analysed. Thus, the report includes – inter alia – an assessment of the market impacts of the 2003 CAP reform in the European Union, an evaluation of the implications for oilseed markets of different rates of growth in Brazilian oilseed production, the potential market implications of a rundown in the huge level of grain stocks held by China and the possible interaction between milk quotas and other instruments to achieve specific milk policy objectives. It also presents results of ongoing work on the introduction of stochastic elements in the baseline generation. Finally, the report includes a background section on the Indian agricultural sector covering the evolution of the main agricultural industries, policy settings, world trade integration and trade prospects. The fully documented outlook database, including historical data, projections and selected scenario results, is available through the OECD internet site."
Please note that from 2005 on, the OECD Outlook was prepared in cooperation with the FAO.

The OECD (2004a) concluded that population and income growth result in broad-based **consumption** gains, especially in the non-OECD region, while **production** expands even faster. This is illustrated by the following table, displaying moderate consumption and production increases in OECD countries, but steep increases in non-OECD countries. More interestingly, the table clearly shows projections of overall wheat, rice and coarse grains production to increase much more rapidly than consumption, though production and consumption of animal products remains balanced.

Table 3.9 Consumption and production growth rates 2003-2013 (OECD, 2004a).

	Consumption growth rate (%)			Production growth rate (%)		
	Total	OECD	NON-OECD	Total	OECD	NON-OECD
Wheat	1.2	0.8	1.4	1.8	1.5	2.0
Rice	0.8	0.8	0.8	1.3	1.1	1.3
Coarse grains	1.3	0.8	1.8	1.6	1.4	1.8
Coarse grains used for feed	1.5	1.0	2.1	n.a.	n.a.	n.a.
Oilseeds	n.a.	n.a.	n.a.	2.7	2.5	2.8
Oilseed meal	2.6	1.6	3.8	2.6	2.2	2.9
Beef	1.5	0.4	3.0	1.6	0.6	2.8
Pig meat	1.5	0.8	2.0	1.5	0.8	2.0
Poultry meat	2.0	1.7	2.5	1.9	1.7	2.1
Butter	2.3	0.4	3.3	2.2	0.0	3.8
Cheese	2.0	1.7	2.8	2.0	1.6	3.4
Skim milk powder	1.0	0.0	2.3	0.7	-0.7	5.6
Whole milk powder	2.6	1.7	2.8	2.6	1.9	3.4
Vegetable oils	2.9	1.7	3.8	3.0	2.0	2.9
Sugar	1.8	0.5	2.2	1.7	0.5	2.2

As mentioned before, OECD projections focus primarily on consumption, production and trade in OECD countries and from an economic perspective, displaying a heavy bias towards markets and policies. Though they are annual, the time horizon is 10 years, so the most recent outlook considers the period 2006-2015. Geographic resolution is by country. Demographic and particularly economic aspects are explicitly taken into account, but diet characterisation is at best implicit. The 2005, 2006 and 2007 projections (OECD and FAO, 2007) were done in cooperation with the FAO, so the main added value of the OECD projections when compared to the FAO projections may be in the economic aspects.

3.4.4 IFPRI

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):
"In this analysis we use the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) to project three future global food scenarios. IMPACT is a representation of a competitive world agricultural market for 32 crop and livestock commodities, including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, oilcakes and meals, sugar and sweeteners, fruits and vegetables, and fish. It is specified as a set of 43 country or regional submodels, within each of which supply, demand, and prices for agricultural commodities are determined. The country and regional agricultural submodels are linked through trade, a specification that highlights the interdependence of countries and commodities in global agricultural markets. The model uses a system of supply and demand elasticities incorporated into a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Demand is a function of prices, income, and population growth. Growth in crop production in each country is determined by crop prices and the rate of productivity growth. The model is written in the General Algebraic Modeling System (GAMS) programming language. The solution of the system of equations is achieved by using the Gauss-Seidel method algorithm. This procedure minimizes the sum of net trade at the international level and seeks a world market price for a commodity that satisfies market-clearing conditions. Additional technical details about IMPACT methodology can be found in Rosegrant, Meijer, and Cline (2002).

IMPACT generates annual projections for crop area, yield, production, demand for food, feed and other uses, prices, and trade, as well as livestock numbers, yield, production, demand, prices, and trade. The current base year is 1997 (using a three year average of 1996–98) and the model incorporates commodity data from FAOSTAT (FAO 2000); income data from the World Bank (World Bank 1998, 2000b) and the United Nations (United Nations 1998); a system of supply and demand elasticities from literature reviews and expert estimates; rates for malnutrition from ACC/SCN (1996); WHO (1997); and calorie-malnutrition relationships developed by Smith and Haddad (2000). While the original version of the model made projections to the year 2020, the more recent version of the model used in this paper projects to 2050. Additional details can be found in Rosegrant, Meijer, and Cline (2002).”

For the purpose of our Biomass Assessment at first sight there seems little added value when compared to the FAO analyses. By the same token, primarily economic analyses (Van Wesenbeeck et al., 2006) by the Dutch LEI (GTAP model) and SOW (GEMAT model) may fit in the same category.

3.4.5 Other issues concerning food demand projections

Other global overall food demand estimates with a similar level of detail are rare. However, in addition to those mentioned above, there are several important studies bearing on the underlying parameters and/or on certain aspects (Evans, 1998; Gerben-Leenes and Nonhebel, 2002; Nierenberg, 2006b; Smil, 2000; Wirsenius, 2003). In addition, attention should be drawn to the special issue of the Journal of Industrial Ecology (2004) vol. 7 (nr. 3/4) on biobased products for more information on the biorefinery concept, since by analogy to refining oil, crops may be separated into a cascade of successive fractions, yielding food, feed, materials and energy carriers. Indeed, food and biofuel production may or may not be competing for land and water, depending on the temporal perspective (Hunt et al., 2006).

Interestingly, six global scenarios for food systems have been evaluated elsewhere (Zurek, 2006), be it for a somewhat different purpose, i.e. focusing on food security. Nevertheless, that study, authored by a FAO employee, refers to three key questions that are also relevant to the present report on biomass: 1) what are plausible changes in environmental and socio-economic conditions that will affect food systems, 2) which elements of existing global scenarios are most important for regional-level food systems analyses, 3) how best can global scenarios be linked to the regional scale so as to capture regional-level factors relevant to food systems? SRES, GEO-3, Millennium Assessment, Global Scenarios Group, IFPRI and FAO scenarios and food projection exercises were compared regarding the key drivers a) economic development, b) population growth, c) technology development, d) main objective, e) attitude towards environmental protection, f) trade and g) policies and institutional development.

Zurek (2006) came to the conclusion that, although both IFPRI and FAO work cover almost all food related variables, not all variables are covered completely by any of the exercises. Food availability is judged to be covered quite well and so are “plausible developments in food demand”. The qualifications are added that food accessibility is less covered and mainly addressed via food price variables and assumptions about market functioning. If food utilisation variables are at all addressed, it is via qualitative assumptions about food safety issues, for example. It is concluded that food preferences and the nutritional value of diets are rarely addressed. Finally, none of the exercises are considered to deal specifically with global environmental change (GEC) vs. food systems interactions. If at all, just the GEC impacts on food production variables are assessed, but questions such as a) how increased risk of flooding may affect food accessibility, or b) how desertification, via labour migration, might have an impact on food systems stability, are only addressed by two exercises (GEO-3, Millennium Assessment) and then only indirectly. Even though the review focus has a slightly different perspective, it is clear that the six projections under review should be adapted to redress their present shortcomings.

3.5 Evaluation of biomass potential studies from a food demand perspective

3.5.1 Introduction

So far, the present chapter focused primarily on food demand and its key drivers. It was argued that, ideally, a study estimating food demand should at least take into consideration 1) world population, 2) economic aspects (including income and food prices), 3) production systems and, last but not least, 4) diet characterisation, 5) in sufficient geographic and temporal detail. Subsequently, several global projections of food demand were evaluated with regard to these criteria. Since the purpose of the present study is, rather, to evaluate biomass potential estimates, such will be done from a food demand perspective. In the following sections, therefore, several of the biomass potential studies touched upon in chapter 2 will be reviewed with respect to the same five criteria used to evaluate food demand estimates.

3.5.2 The study by Hoogwijk et al. (2005)

The focus of the study by Hoogwijk et al. (2005) is on biomass from woody energy crops only. Therefore, food demand assumptions derive from the underlying 4 SRES scenarios primarily (see below). Daily caloric food intake as a metric is insufficient, and should at least be supplemented with daily protein intake. The sensitivity analysis (on page 244) seems to contain a plausible list (from a food demand perspective) for the distinctive criteria underlying the 4 SRES scenarios: population growth, GDP development, technology development, diet, trade globalisation. A shift of climate zones by climate change seems to be addressed. In that respect attention should be paid to a December 2006 essay anticipating both agriculture and tourism in Europe to move North, away from the Mediterranean (Veerman, 2006). The study's assumption that the production of energy crops should not affect food and forestry production, nature reserves (or biodiversity) and animal grazing seems a sensible one, in particular with regard to grazing and grasslands. The assumption that abandoned agricultural land is to be taken out of production indefinitely (i.e. beyond the year 2100) is completely counterintuitive from the food demand perspective, for conditions may change rapidly. In conclusion, non-productive land is probably overestimated, economic growth plus the concomitant diet change in China, India and booming South American economies have not been incorporated yet; protein diet change and use of concomitant carbohydrate by-products are neglected. In conclusion, this study supplies a transparent estimate of food demand, but - assuming the global standard of living and the concomitant consumption of animal products keep rising - it seems likely that future food demand is underestimated and, therefore, biomass potential is overestimated.

3.5.3 The report by Perlack et al. (2005)

In the report by Perlack et al. (2005) food demands for the US are directly linked to population growth: “Projections suggest that the North American population will increase by 37 percent between 2001 and 2050 while the world population increase will be only slightly higher. Thus, in the highest crop yield scenarios corn required for food in the United States is assumed to increase by 37 percent over the 2001 value.“ This might be a reasonable assumption for the USA, but it would undoubtedly underestimate global food demand. World population growth is accounted for via export projections derived from FAO data (Perlack et al., 2005: 30), however, worldwide increasing incomes and concomitant meat consumption seem largely neglected. Diet change, in fact, is approached in an off-hand, but utterly incorrect way (Perlack et al., 2005: 33): “Second, it is just as logical to assume that future meat demands will decline rather than increase. Populations will be aging, thus requiring less protein for sustenance. Further, trends towards healthier eating practices may cause reduced meat demand, at least in the industrialized countries.” Though the latter may come true, the former is clearly in error, for aging people do not require less protein for sustenance (Health Council of the Netherlands, 2001). In fact, protein turnover hardly varies with age. In conclusion, this study is focusing on the USA, treating the rest of the world as a black box for export. Therefore, it supplies a very unreliable estimate of food demand, which seems severely underestimated. In consequence of their own assumptions, their biomass potential will be severely overestimated.

3.5.4 The study by Smeets et al. (2007)

As explicitly stated on page 60, the study by Smeets et al. (2007) does not distinguish between “intake”, “demand” and “consumption” of food. Moreover, the estimates are based on FAOSTAT data, which describe “supply” (production + imports - exports), and which are inherently unreliable though, admittedly, there is little alternative data available. Concerning population growth the FAO position is referred to: “Population growth has been responsible for 80% of the increase in food consumption between 1970 and 1998 and probably will remain the key driver of increasing food consumption during the coming decades (Bruinsma, 2002).” In this respect, the following qualifications have to be made: 1) it is unclear whether the 80% concerns monetary value or weight of food products, 2) such metrics do not reflect environmental impact or resource use (such as land use) very well, and 3) they do not reflect diet change very well. In other words, it may well be that diet (or income) should be characterised as a more important driver of food consumption than population in the near future. At any rate, per capita consumption is also extrapolated from the FAO (Bruinsma, 2002) and, therefore, diet change is insufficiently addressed. Daily caloric food intake as a metric is insufficient (even when distinguishing between plant and animal products), and should at least be supplemented with daily protein intake (see below). In conclusion, this study does not supply a transparent estimate of food demand, but - assuming the global standard of living and the concomitant consumption of animal products keep rising - it seems likely that future food demand is underestimated and, therefore, biomass potential is overestimated.

3.5.5 The paper by Wolf et al. (2003)

The paper by Wolf et al. (2003) itself has not been evaluated in detail, but the underlying report (Luijten, 1995) has been studied extensively. In fact, both the underlying data for food demand (1995), and for population projections (1997) should be qualified as obsolete. Furthermore, a crude attempt has been made to include diet effects, but at a very general level. For all these reasons, this paper yields an unreliable estimate of food demand. Moreover, the impacts of HEI (high external input, i.e. of fertilisers and pesticides) are underestimated and the potentially available land area is overestimated (conversion of grasslands or natural land is not a good idea). Therefore, the biomass potential of HEI systems is grossly overestimated. The biomass potential of the LEI systems may be somewhat underestimated, though, since bioenergy from agricultural residues and wastes seems to have been disregarded.

3.5.6 A future shift in the present diet trend?

In 1998, the Dutch average recommended daily intake (RDI) of protein was 50 grams (Health Council of the Netherlands, 2001), when age and sex differences are disregarded. However, the average daily consumption was 80 grams (Voedingscentrum, 1998), some 60% more. Finally, the supply was 106 grams (FAO, 2005). The difference between consumption and supply is generally wasted, which is in agreement with the 20-25% generally found in the literature (Quist, 2000; Smil, 2000). Evidently, the Netherlands is a far from representative country globally. Even in Europe the variation in protein sources in the national diets is huge and sometimes surprising (De Boer et al., 2006), let alone on a global scale. In 1999, on average 41.9 grams of plant proteins and 66.7 grams of animal protein *supply* were “consumed” per day in EU-15. Assuming 25% waste, the European animal protein supply almost exactly equalled the Dutch RDI, on top of the plant protein consumption, which already satisfied over 60% of the Dutch RDI.

Globally, demand of meat and fish products is still on the rise and so are the environmental impacts of their production. Inevitably, the prices of meat, fish, soy and cereals will rise also. Whether for environmental reasons, exploding prices, or - more likely - a combination, a trend reversal towards diets containing less animal proteins and more plant proteins seems inevitable. Such a diet change will have a huge impact on the biomass potential, due to the fact that circa 6 kg of plant protein is required to produce 1 kg of animal protein. Much will depend, therefore, on the extent of a diet shift. A new equilibrium between plant products and animal products, however, is likely to be critically dependent on economic variables such as income and relative and absolute prices of the commodities under scrutiny, i.e. meat, fish, milk, eggs, cereals and soy.

In this regard, it is interesting to reiterate some of the concluding remarks of a paper on economic aspects cited earlier (Keyzer et al., 2005). On the consumer side, per capita meat demand will rise faster than would be predicted on the basis of fixed income elasticities, because in most developing countries a significant part of the population has just entered or is on the verge of accessing the income bracket where a significant fraction of income growth is spent on meat. On the producer side, feed/meat ratios in developing countries will increase in the next few decades, rather than fall, as is commonly assumed in most projection models. The reason for this is that the traditional sources of animal feeds are supplied as residuals that are becoming increasingly scarce and can no longer be regarded as free input. These results seem to be robust against alternative assumptions on income growth, technological progress in feeding, yield increases, and cropping intensities.

In order to get a feel for the order of magnitude of a potential diet change we'll make a loose estimate of the minimum protein requirements. For the sake of the argument let us assume the Dutch average (age and sex neglected) RDI of 50 g/day as the worldwide standard. Adding a conservative 20% (present consumption in developed countries is much higher) adds up to 60 grams of protein that is nutritionally required as a generous minimum. If only one third (20 g) of this protein were supplied by meat this would boil down to circa 60 grams of meat per person per day, since on average meat consists for about a third of protein. Adding 25% which is currently wasted, daily per capita meat *supply* would be 75 grams and annual per capita meat *supply* would be 27.4 kg. Therefore, the 6 billion people around in the year 2000 would have required 164.4 million tons, when the actual supply was 233 million tons, some 40% more, in spite of severe local undernourishment. If - like the FAO stated in 2002 - 8.27 billion people were to be around by the year 2030 (table 3.8), 226.6 million tons of meat would be required, rather than the 376 million tons projected (table 3.8), some 66% more. Conservatively estimated, therefore, we may conclude that - without putting a healthy nutrition in jeopardy - world 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 and one third of our protein consumption would still derive from meat.

If, in fact, consumers in developed countries were to reduce their overall protein intake by about one third, and replace their intensively produced meat by either plant-derived protein products or extensively produced meat, the majority (87-94%) of prime agricultural land currently used for feed crops (400 million hectares) might be set free, and become available for (high yields of) biomass and/or to reduce the stress on nature and freshwater (Aiking et al., 2006a), with additional health benefits, including reduced zoonotic disease such as avian influenza.

3.6 Conclusions

Due to increasing world population and affluence, certain human activities with huge environmental impacts – rather than gradual improvement – require a radical systems change, i.e. a societal transition. Recognised targets for transition include the production and consumption of food, energy and water. Notably, food production appropriates about 75% of available freshwater, 35% of land and 20% of energy. Within the food area, meat production has a disproportionate environmental impact via both resource utilisation (land use, biodiversity, freshwater) and pollution (climate change, pesticides, eutrophication). Therefore, food demand is a complex issue. Though primarily dependent on world population, geographic, economic and socio-cultural aspects also play important roles, as is shown by the strong coupling with diets.

The principal food demand projections are by the FAO. They take freshwater resources into account, but biofuel production is not addressed. Overfishing is acknowledged, but crop demand by aquaculture is not. Further intensification of livestock production is cheered without even mentioning the concomitant risk of emerging zoonotic diseases such as avian influenza. Projections are at a general, aggregate level and quite optimistic with regard to yield increases and the effects of climate change. It is concluded that 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 FAO and World Bank, detailed projections of their development and future contributions to world food production are lacking altogether. In general, FAO seems to implicitly and explicitly favour further intensification of agriculture, without paying much attention to the potential of organic production. By the same token, the biorefinery concept has not been integrated in mainstream FAO thinking yet.

Notwithstanding, in a recently published report (Steinfeld et al., 2006) on the environmental impacts of livestock production, explicitly addressing climate change, water depletion and pollution, and biodiversity, the FAO came to the conclusion: “An important general lesson is that the livestock sector has such deep and wide-ranging environmental impacts that it should rank as one of the leading focuses for environmental policy: efforts here can produce large and multiple pay-offs. Indeed, as societies develop, it is likely that environmental considerations, along with human health issues, will become the dominant policy considerations for the sector.”

Four of the biomass potential studies touched upon in chapter 2 have been reviewed with respect to the same five criteria used to evaluate food demand estimates. From a food demand perspective, the study by Hoogwijk et al. (2005) came out ahead of the rest, but in all four studies - assuming the global standard of living and the concomitant consumption of animal products keep rising - it seems likely that future food demand is underestimated and, therefore, biomass potential is overestimated.

The production of food products of animal origin, such as meat, dairy products (and even fish in aquaculture) play a key role in land and water resources appropriation by food production as a whole and, consequently, on biomass potential. To a very large extent, therefore, is likely to be the key factor determining overall food demand, and its impacts on the environment and on natural resources. Unfortunately, the demand for animal food products magnitude is inherently hard to estimate.

3.7 References Food

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4 Water

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4.1 Summary Water

4.1.1 Introduction

Only 0.26% of all water on earth is contained in lakes, reservoirs and river systems, which are the main sources for human water use and for sustaining water ecosystems (Shiklomanov, 2000, Seckler et al., 1998). Large regional differences in these renewable water resources exist, leading to a very diverse picture of water availability over the world. 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. Not only large differences in absolute amounts of water resources exist, but also annual variability is differs enormously between regions. Especially in arid and semi-arid regions, where water volumes are small, annual variability is large.
A common classification of water resources is that in blue or green water flows. Blue water flows refer to water in rivers, lakes and groundwater, while green refers to water in the rooted zone of the soil originating directly from rainfall, which 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).
Global annual renewable water resources are estimated at 43,000 – 47,000 km^3 (Shiklomanov, 2000; Seckler et al., 1998), but only around 25% (12,500 km^3) of this blue water is accessible, i.e. can be withdrawn from rivers and aquifers for human purposes (Molden et al., 2007). Reason is that 20-50% of the water, depending on the local situation, is required for environmental requirements and services. Water is mainly used for domestic purposes, in industries, in agriculture and it is evaporated from large reservoirs. Only the water lost by evaporation is lost for use in any of the other sectors.

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%. This amount of water is actually removed from the system through crop water depletion. 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 is another indicator used for assessing the efficiency of water use, usually including both rainfall and irrigation. WP can refer to physical yields, but also to monetary yields per unit of water. It may refer to irrigation water use, to transpiration or to evapotranspiration. Crop water productivity is used as an indicator of crop yield per unit of water consumed (evapotranspiration). In this definition CWP for energy and food crops can differ due to use of different crop parts. Basin water productivity refers to beneficial non-agricultural water uses also. Hence, an optimum between production per m^3 water and production per ha should be searched (Bessembinder et al. 2003)..
Water use by crops can be simulated based on weather date and crop growth (study 4) or by a crop specific *Water Use Efficiency*. WUE varies among crop types. Generally, WUE and productivity of C3 crops is lower than of C4 crops[1]. However, WUE varies with weather, growing period and agricultural practices, such as timeliness of operations, nutrient application (if

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[1] C$_3$ crops include temperate crops, such as small grains, including rice, potatoes, leguminous species, temperate grasses; C$_4$ crops include millet, sorghum, sugarcane, tropical grasses, miscanthus,

nutrients limit crop growth WUE will be lower), incidence of pests, diseases and weeds (Bessembinder et al). The water source is not included in the WUE.

4.1.2 The ideal study

The ideal study does not exist. As the introduction shows that to be able to assess the potential of biomass production for energy supply, several very divergent aspects have to be considered with respect to water.

First of all, it is crucial which questions have to be answered at which scale. 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. Going from lower to higher scales some parameters will disappear and others will be added to the list. Moreover, aggregation of results is always accompanied with loss of information, e.g. by averaging out heterogeneity. Generally, the higher the scales refer to longer time periods and the lower scales to shorter time periods.

Having said this, the water requirements for food and other agricultural commodities, for industry, for domestic use and for environmental services have to be assessed. These requirements depend on technology used, population size, human diets etc. In addition, none of these aspects is static, but they all change in time. These are relatively long term developments, and hence require assessment at one of the higher scales. The priority given to each of the different uses (human, domestic, agriculture, environmental services) determines the availability for bioenergy crops.

Studies at the scale of a river basin should include water availability and water management at this scale, required water for food production from that basin and other water uses, water use efficiency or water productivity at basin scale. The required production of agricultural commodities (food, feed, fibre) determines input levels of nutrients and water. This should be compared with actual water (and nutrient) productivity and existing or expected bottle necks for water availability for bioenergy crops have to be identified. Possible solutions, if any, have to be explored. Crucial parameters are climate, but preferably weather data (rainfall, temperature, radiation), land use, soil type on a regional scale. Farm types can be classified.

At the farm and field scale, similar parameters are required, but at a more detailed level. Weather variability is important, risks on crop failure due to erratic rainfall. Land use has to be detailed in terms of cropping systems and rotations. These determine water use for agricultural commodities. Limitations to water availability at farm scale have to be assessed. This may come from rainfall or from water requirements elsewhere in the region and then is an exogenous parameter for the farm.

Many possible scenarios can be explored with a wide variety of pictures painted.

Realistic possibilities for improving water productivity at a range of scales have to be assessed. Of course, the less accurate the parameters are assessed the less accurate the explorations on water availability for energy crops will be. As priority is often given to the other uses, all uncertainties and inaccuracies are accumulating in the final assessment of the scope for energy crops.

It should be noted here that at each scale different stakeholders act in the arena and different decision makers are in charge. Hence, although some improvements seem very obvious, conflicting goals and hierarchical structures may hamper or help improving the scope for bioenergy crops.

4.1.3 Results

Global/regional scale

Several leading studies on water resource use at global and regional scale have been reviewed (…). The main results are discussed in this section. Some studies are based on analyses of measured and statistical data and national data bases. Others use simulation models to estimate water use. This are two principally differing approaches, each with their own merits and drawbacks.

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% (Ch4, Shlikomanov, 2000). However, the largest part of this (80%) flows back to rivers, lakes or groundwater. For agricultural water withdrawal estimates vary considerably depending on the scenario on population growth, diet and input levels used, but in all scenarios it is increasing anyway. Energy crops are not considered explicitly in these studies.

Figure 4.S1 shows water withdrawal by region and sector according to FAO data (Sophocleus, 2004)

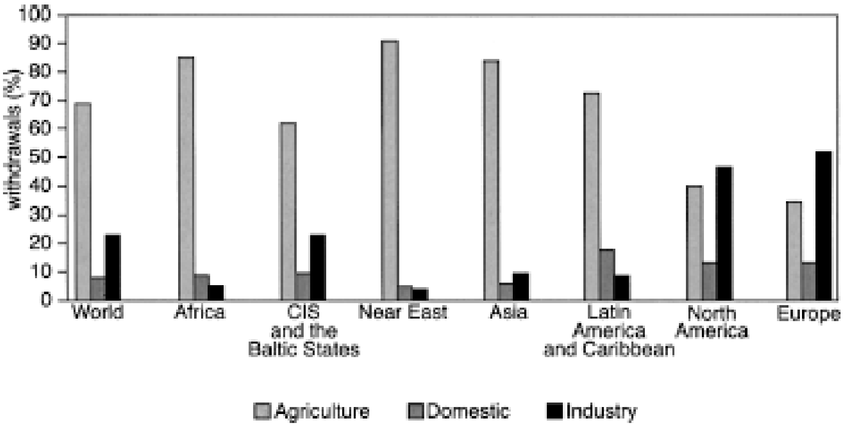
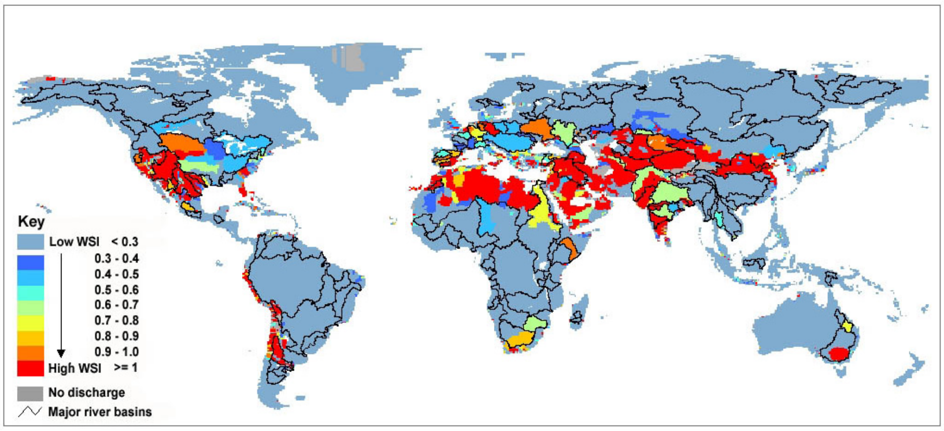


Figure 4.S1 Water withdrawals by region and by sector (adapted from FAO)

The environmental water requirement is another factor often not considered. This is the water which cannot be withdrawn without damaging ecosystems and ecosystems services. It is estimated at 20-50% depending on the local situation. Total water requirements and availability, including the environmental water requirements (EWR) have been estimated by Smakthin et al. (2004). They expressed demand and availability in a water stress indicator WSI



This picture is in line with other sources (Shlikomanov, Molden et.al, 2007)

Field and farm scale

At field and farm scale utilization of rainfall and efficiency of irrigation systems are major determinants in water requirements. As mentioned before, this is highly variable, depending on many factors, such as climate, bio-physical conditions, land use, management system. Examples can be given of different irrigation systems, their efficiency and Crop WUE, but the actual potential for energy corps at lower scales can only be assessed in cases, where the appropriate data for that case can be selected and possibilities for energy crops can be explored. The map in Figure 4.2 gives a rough indication on high and low potential regions.

Water use efficiency of crops

Water use efficiency (WUE)can be expressed both in terms of total evaoptranspiration (ET), including non-productive soil evaporation, and in terms of transpiration (T).

WUE is variable, because of variations in crop characteristics (especially the difference between C_3 and C_4 crops and weather conditions. Generally, WUE and water productivity of C_3 crops are lower than those of C_4 crops. When expressed in terms of ET, the variability increases, because rainfall pattern and crop management also affect the magnitude of losses through soil evaporation.

A high WUE can only be achieved if other factors (nutrient availability, incidence of pests and diseases, appropriate and timely management) are not limiting crop production. If one of them is limiting, the actual water use efficiency for biomass production is less than the potential. Hence, in different regions of the world large variations in actual WUE are found. A compilation of WUE –values is given in the report.

The part of the crop used for bio-energy varies strongly among crops, so WUE for total crop dry matter production does not necessarily indicate the water use efficiency for energy production. In addition, some crop residues can be processed for heat or electricity (bagasse from sugarcane). Hence, allocation of water use to multiple (by)products is a point of discussion that cannot be overlooked when assessing WUE.

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. Considering only the potentials is too simplistic.

Alleviating water stress:

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. As water is a scarce resource in many regions, especially in those with semi-arid climates, the scope for energy crops will improve if water availability increases. Below is short list of the various measures mentioned:

All sectors

- Decrease use in industries
- Better utilization of local water
- More recycling of industrial and domestic water
- Use of static water (ice)
- Redistribution between territories
- Water conservation
- Change diets towards less water consuming foods
- Agricultural trade: produce where water is and then transport products (virtual water)

For agriculture:

Rainfed:

- improve water productivity by water harvesting and supplemental irrigation
- expand area

Irrigated:

- in irrigation: use clean waste water, groundwater, storage
- improve water productivity, integrate livestock and fisheries
- better maintenance of systems
- general:
- decrease yield gap between actual and potential by decreasing optimizing crop management (nutrient availability), post-harvest losses, processing losses, losses due to pests, diseases and weeds.

Climate change

Most studies on the relation between water availability and climate change indicate that total rainfall will increase due to enhancement of the hydrological cycle by global warming and that variability of rainfall patterns and the number of extreme weather events will increase. The models agree on the order of magnitude, but the spatial pattern varies. In general, rainfall is expected to increase in high latitude areas and to decrease in most (sub-)tropical areas, enhancing water scarcity in at least some of those areas.

4.1.4 Discussion and conclusions

Most studies observe a relation between poverty, hunger and water stress, leading to problems especially in arid, semi-arid sub-humid climates. 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. However, in regions with water scarcity these opportunities appear to be absent, at least at rather large scale.

A major point of discussion is that improvements of water productivity at field/plot scale cannot be extrapolated straightforward to higher scale, because we have a situation here where ‘water losses’ upstream are available for use downstream; when efficiency of water use upstream increases, there may be less water available downstream. 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 projections for the future
- 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. Effects of climate change on regional water availability is very uncertain, but generally it is expected that water scarcity will increase in the (sub-)tropics. If these areas are already water scarce, this will increase water stress in agricultural production systems, and hence, decrease the opportunities for bio-energy production in these regions..

4.2 Introduction

The rapidly increasing demand for biofuels, based on biomass brings the issue of competition of food, fibre and feed crops for resources, such as land, nutrients and also water, to the fore. In several studies estimates have been made of the world’s potential for bio-energy crops. In this section we pay special attention to implications of increased biofuel production for water use, as well as the implications of expected changes in water availability on possibilities for biofuel production. First of all it should be noted that the scale at which water resources and water use are analysed influences the pictures painted to a large extent.

At the global scale, about 12% of current energy needs are derived from biomass, including energy crops, crop residues, wood and dung. However, in Sub-Saharan-Africa the share of biomass is close to 60%, while in the OECD countries it is only 2% (Millennium Assessment, 2003). In the Millennium Ecosystem Assessment, various scenarios have been explored. Let’s take one of them as an example to illustrate the effects of increasing amounts of biomass for energy. The TechnoGarden-scenario assumes that by 2050 biomass will contribute 25% to total global energy use. Although competitive land use was included, the impact of biofuel production on water resources is not included (Alcamo et al., 2005). The indicated amount of biomass for fuel will require about 8,000 million tons of woody biomass. Assuming average values for water use efficiency (13.3 kg DM/ (ha*mm) ET) and yield (230 GJ/ha), this will result in 5,500 km^3 crop water use and requires 500 million ha of land. Current values for food production are 7,600 km^3 and 1,500 million ha crop land (Fraiture et al., 2007; Oki & Kanae, 2006). This type of rough calculations sets the scope for the possibilities for bioenergy in relation to water use and food production. Emerging questions are where should the extra water required come from? How much water is available? What is the distribution of water resources and use over the world? When and where will competition with food production be problematic? How does water for bioenergy compete with other uses?

In this chapter, first global water resources and water use for various purposes are reviewed. Subsequently, we look at various scales and examine resources and use at regional scale (natural-economic regions) and crop scale. Finally, the studies and references used in this chapter are described in more detail, including the underlying assumptions and calculation methods.

4.3 Global water resources

Of the total amount of water in the hydrosphere, only 2.5% is freshwater and the remainder is saline. The largest part of the freshwater is fixed in permanent ice and snow, about 30% is fresh groundwater and only 0.26% of all water on earth is contained in lakes, reservoirs and river systems. These latter water systems are the main sources for human water use and important for sustaining aquatic ecosystems (Shiklomanov, 2000, Seckler et al., 1998).

In hydrology and water management, freshwater resources are often characterized as either static or renewable resources. Static refers to freshwater with a full renewal of many years or decades where intensive use will lead to storage depletion, often with serious ecological consequences. Renewable water refers to annual replenishment in the process of water turnover on earth. It consists of river runoff, inflow of groundwater into the river systems and recharge of upper aquifers. River runoff provides the major part of global human water use. Total annual precipitation on the world land area, including fresh water lakes is estimated at 108,000 km^3 of which about 61,000 directly evaporates into the air. Global annual renewable water resources are estimated at 43,000 – 47,000 km^3 (Shiklomanov, 2000; Seckler et al., 1998), but only around 25% (12,500 km^3) of this 'blue water' is accessible, i.e. can be withdrawn from rivers and aquifers for human purposes under full development of storage and conveyance facilities (Seckler et al., 2002; Rockström et al., 1999). Reasons are that runoff in rivers is often in peaks, which makes it difficult to use the water, and that much of the global runoff occurs in regions where its use is difficult, such as the Amazon, Russia, and Bangladesh. Water for environmental services should also come from this amount, but only partly, as it can also partly be met from non-utilizable water. This complicates the transparency of the picture.

Another classification is that in blue or green water flows. Blue water flows refer to water in rivers, lakes and groundwater, while green refers to water in the rooted zone of the soil, originating directly from rainfall that is available to plants. Global renewable water is similar to global blue water. Globally, around 80% of agricultural evapotranspiration (crop water depletion) originates directly from rainfall (green water), while the remaining 20% is provided through irrigation (blue water withdrawals) (Fraiture et al., 2007).

All figures mentioned so far are global averages. However, large regional differences in renewable water resources exist, leading to a very heterogeneous picture of water availability over the world. Hence, quantification of the spatial and temporal distribution of river runoff and assessment of the influence of humans form the backbone for decisions on optimal use of water resources. This information has been summarized by several researchers. The data collected by Shiklomanov (op. cit.) are given in Table 4.1, as an example. Other authors often use this source as basic data for their calculations, sometimes complemented with new data or some more recent data from individual countries. Table 4.1 shows large spatial differences in water resources. The coefficient of variation shows large temporal variability. Especially in arid and semi-arid regions, where water volumes are small, annual variability is large.

Table 4.1 Renewable water resources, potential availability and water use per capita and per area for the continents in the world and distributed over 26 natural economic regions.

		Area 10^6 km	Population million	Average resources (km^3/yr)		Potentially available (km^3/yr)*	c.v.	Withdrawal (km^3/yr) 1995	fraction withdrawal of resources
				inflow	territory based average				
	Europe	**10.46**	**684.7**		**2900**	**2900**	**0.08**	**455**	16
1	Northern	1.32	23.2		705	705	0.08	11	2
2	Central	1.86	293	6	617	620	0.21	154	25
3	Southern	1.79	188	109	546	601	0.18	186	31
4	North of European part FSU	2.71	28.5	27	589	603	0.1	11	2
5	South of European part FSU	2.78	152	123	443	505	0.18	95	19
									0
	North America	**24.3**	**453**		**7890**	7890	**0.06**	**686**	9
6	Canada and Alaska	13.67	29	130	4980	5045	0.06	56	1
7	USA	7.84	261	70	1800	1835	0.17	503	27
8	Central America, Caribbean	2.74	163	2.5	1110	1111	0.1	127	11
									0
	Africa	**20.1**	**708**		**4050**	4050	**0.1**	**219**	5
9	Northern	8.78	157	140	41	111	0.34	110	99
10	Southern	5.11	83.5	86	399	442	0.14	27	6
11	East	5.17	193.5	26	749	762	0.11	53	7
12	West	6.96	211.3	30	1088	1103	0.28	27	2
13	Central	4.08	62.8	80	1770	1810	0.09	3	0
									0
	Asia	**43.5**	**3445**		**13510**	13510	**0.06**	**2231**	17
14	North China, Mongolia	8.29	482		1029	1029	0.23	268	26
15	Southern	4.49	1214	300	1988	2138	0.1	887	41
16	Western	6.82	232		490	490	0.35	249	51
17	South East	6.95	1404	120	6646	6706	0.09	631	9

Continued Table 4.1

		Area	Population	Average resources (km^3/yr)		Potentially		Withdrawal	fraction withdrawal
		10^6 km	million	inflow	territory based average	available (km^3/yr)*	c.v.	(km^3/yr) 1995	of resources
18	Central Asia, Kazakhstan	3.99	54	46	181	204	0.17	154	75
19	Siberia, Far East, Russia	12.76	42	218	3107	3216	0.06	21	1
20	Transcaucasia	0.19	16	12	68	74	0.12	20	27
	South America	**17.9**	**314.5**		**12303**	12303	**0.07**	**167**	1
21	Northern	2.55	57.3		3340	3340	0.15	24	1
22	Eastern	8.51	159.1	1900	6220	7170	0.08	49	1
23	Western	2.33	48.6		1720	1720	0.18	48	3
24	Central	4.46	49.4	720	750	1110	0.17	46	4
									0
	Australia, Oceania	**8.95**	**28.7**		**2404**	2404	**0.1**	**30**	1
25	Australia	7.68	17.9		352	352	0.24	27	8
26	Oceania	1.27	10.8		2050	2050	0.1	3	0
									0
	World total	**135**	**5633**		**42780**	42780	**0.03**	**3788**	9

* calculated as the locally available water plus half of the inflow

4.4 Global blue water use

Water is mainly used for domestic purposes, in industries, in agriculture and by evaporation from large reservoirs and open water bodies. This latter source is often not considered, although water depletion due to evaporation is substantial. Water lost by evaporation is lost for use in any of the other sectors. No reliable estimates are available, but an order of magnitude of open water evaporation is around 1.3% of global rainfall (1,404 km^3) (Molden, 2007b).

In analyzing global water use it is crucial to distinguish between blue and green water. Total global blue water use has increased considerably during the past decades. For 1995 it was estimated at 3,600 km^3, some 29% of accessible renewable blue water (Alcamo et al., 2000; Figure 4.1). Agriculture with 70% is by far the largest user of water and domestic use is smallest with 10%. Similar values are reported by Shiklomanov (2000), Seckler et al., (1998) and Molden et al. (2007). This number is much lower than the total global crop water use of 6,400 km^3, because of the amount of green water used by crops originating directly from rainfall (Rockström et al., 2007).

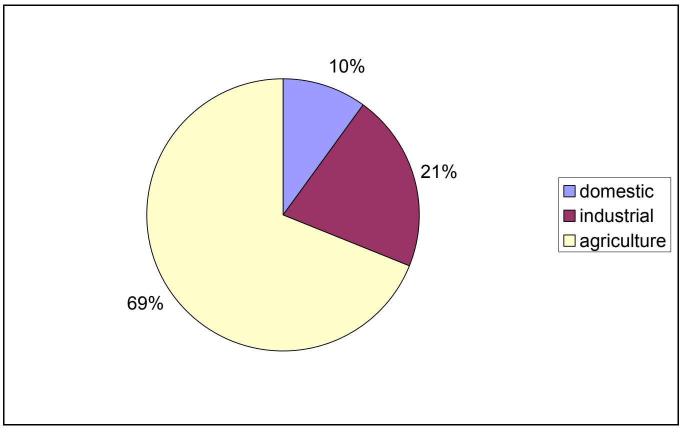


Figure 4.1 Water withdrawal by sector (in %; Alcamo et al., 2000)

Domestic water use strongly varies among regions. In large developed cities it is typically 400-600 litres per capita per day (lcd, i.e. 182 m^3 per capita per year), with 5-10% that is actually consumed. In smaller, less endowed cities, water use is 50-100 lcd (27 m^3/cap.year), with 40-60% that is actually consumed. In regions with insufficient water resources, water use is 10-40 lcd (9 m^3/cap.year). Hence, total water use is dependent on population density, the level of services and utilities and climate (Shiklomanov, 2000).

Industrial water use refers to cooling, transportation, solvent and sales in product. Large differences exist among industries, varying between 1 and 40% of the intake, the remainder being discharged or recycled. It should be noted however, that technological developments stimulate water recirculation, reducing water use. Economic development is the main driver for modifications in this type of water use.

The largest part of water use in agriculture is in irrigated systems. Worldwide, about 20% of agricultural land is irrigated, producing about 40% of our food (Molden et al., 2007; Oki & Kanae, 2006; Shiklomanov, 2000). The large variability in climatic conditions, crops and irrigation technologies results in very different water withdrawal rates. In rainfed systems, covering the remaining 80% of the land area, crop production relies directly on rainfall. Hence, rainfed systems do not withdraw water form the available blue water resources.

Figure 4.2 shows water withdrawal by region and sector according to FAO data (Sophocleus, 2004), illustrating that in Europe and North America the relative share of industry in total water withdrawal is much higher than in other parts of the world.

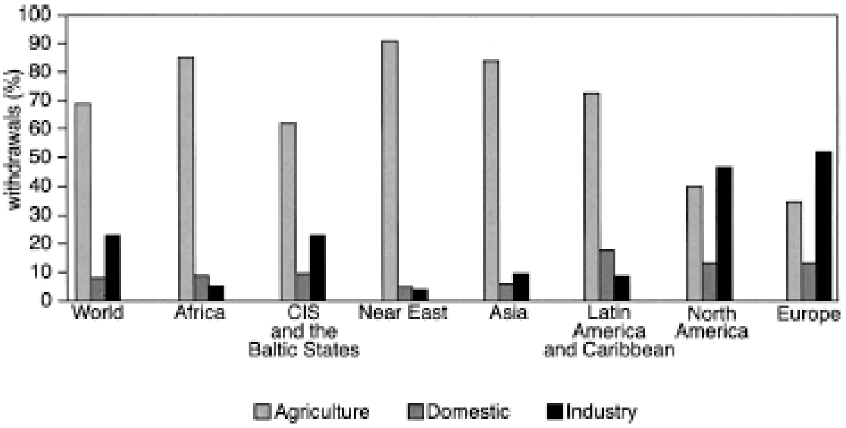


Figure 4.2 Water withdrawals by region and by sector (adapted from FAO)

A global overview of water resources and water depletion (the actual consumptive use of water) is given in Figure 4.3. These values are indicative for the size of the different water flows. The total cultivated area is 1,560 million ha of which some 277 million ha is irrigated (Oki & Kanae, 2006;).

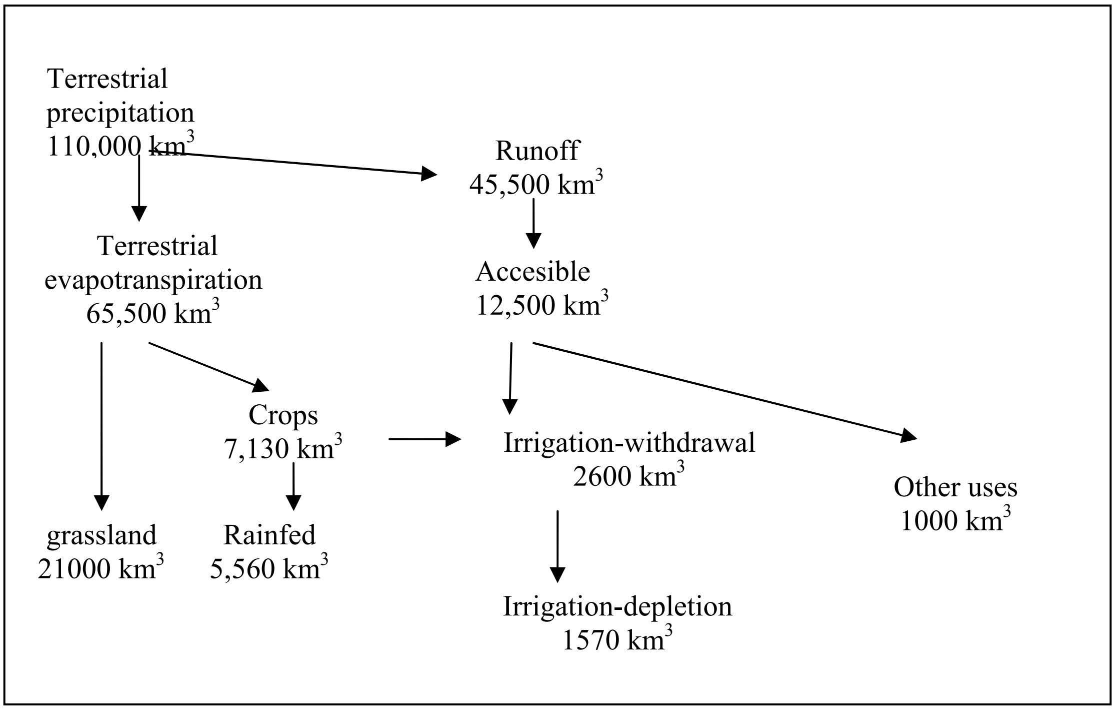


Figure 4.3 Renewable water resources and water depletion by different sectors around 2000 (after Seckler et al., 2000, Fraiture et al., 2007, Rosegrant et al, 2002; Alcamo, 2003; Shiklomanov, 2000; Oki & Kanae, 2006)

4.5 Irrigation efficiency and water productivity

Irrigation efficiency 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%. This amount of water is actually removed from the system through crop water depletion. The ratio of depletion to withdrawals is commonly referred to as the consumptive or depleted fraction (Seckler et al., 2003). It seems very easy to improve irrigation efficiency, but the catch is that the other 60% is not fully lost. Most of it is captured and recycled somewhere else in the system. Only if it evaporates or flows to unusable sinks (e.g. saline reservoirs, the sea) it is lost. If the remaining water is available for further use, and 40% of this water is depleted, then the combined net efficiency becomes 40% + 60%*40% = 64%. As reuse loops of water are very common in river basins, improving irrigation efficiency becomes a much more complex issue, and depleting more water upstream by increasing irrigation efficiency may actually lead to less water being available downstream.

The most recent global assessment of water use in agriculture by Molden (2007a) places current agricultural water depletion from blue water resources through irrigation at 1,570 km^3. To meet this 1,570 km^3, an estimated 2,605 km^3 are withdrawn from rivers, reservoirs, lakes, and aquifers. This means that 60% of the blue water withdrawn for agriculture is actually depleted (i.e. rendered unavailable for further use), while 40% returns to surface water or groundwater without being depleted. (Fraiture et al., 2007)

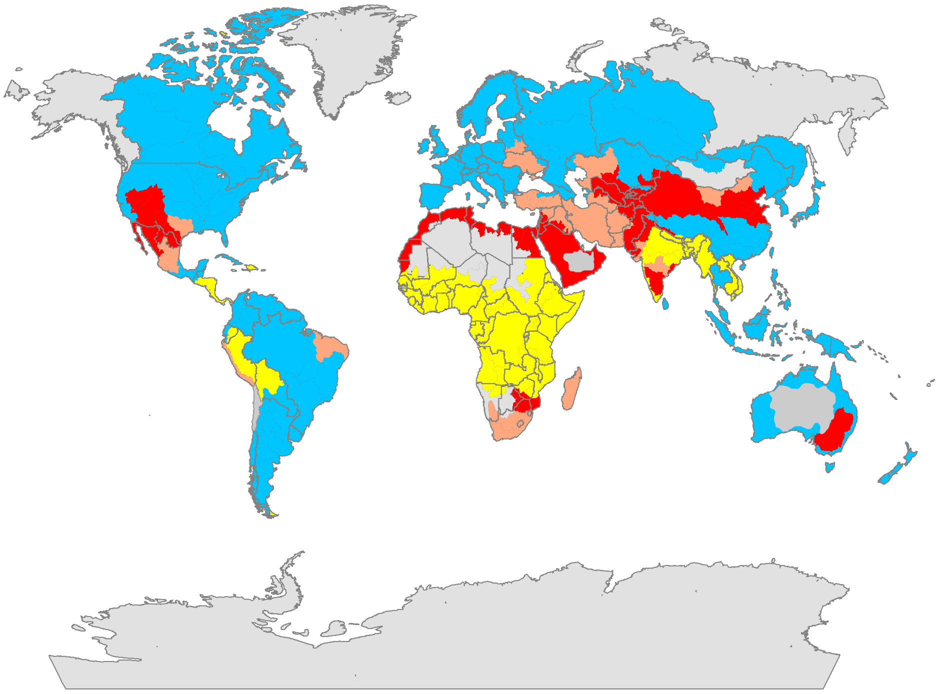
Irrigation efficiency can be improved following two different ways i) by increasing the effectiveness of individual applications, and hence increasing the depleted fraction and reducing the return flows and ii) by increasing return flows that would otherwise flow to unusable sinks. Also a combination of both is possible. Which is the most optimal depends on hydrological, managerial and economic considerations. However, it is clear that looking at the irrigation efficiency at individual farm scale only presents part of the picture.

Hence, it is important to realise that water (re)cycles through the system (water multiplier effect; Seckler et al., 1998). The term water withdrawal usually refers to the amount diverted from a water source, the term water depletion refers to the actual consumption of water that can not be recycled. This makes it necessary to analyse irrigation efficiencies at river basin level, taking into account the use of return flows.

Water Productivity is another indicator used for assessing the efficiency of water use, often including irrigation. WP does not say anything about production levels. It can refer to physical yields, but also to monetary yields per unit of water. It may refer to irrigation water use, to transpiration or evapotranspiration. Crop water productivity is used as an indicator of crop yield per unit of water consumed (ET). Basin water productivity refers to beneficial non-agricultural water uses also. Hence, an optimum between production per m^3 water and production per ha should be aimed at (Bessembinder et al., 2003) and a conclusion similar to that for irrigation efficiency can be drawn: the most optimal value depends on scale and situation.

4.6 Regional water balances

Table 4.1 (Shiklomanov, 2000) illustrates that, globally, water resources are distributed very unevenly and water availability therefore strongly varies among regions. Although total global water withdrawal is only 9% of the potentially available water resources, and 29% of the accessible renewable blue water, regional variability is dramatic (0.2% in Oceania – 99% in North Africa). Other sources give comparable results (Molden et al., 2007; Seckler et al., 1998; Alcamo et al., 2002; Vőrősmarty et al., 2000), with minor deviations. What are the consequences of this heterogeneity in terms of water scarcity? The map in figure 4.4 shows the distribution of physical and economic water scarcity over the world (Molden, 2007b). In physically water-scarce areas, water resources are insufficient to meet all demands. In economically water-scarce areas, water resources are abundant, but human capacity and/or financial resources are limiting adequate use of water resources, e.g. by lack of institutional development, infrastructure, distribution, etc.



Legend:

Red:	Physical Water Scarcity. More than 75% of the river flows are withdrawn for agriculture, industries or domestic purposes (accounting for recycling of return flows). This definition of scarcity-relating water availability to water demand-implies that dry areas not necessarily water scarce.
Light red	More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
Yellow	Economic Water Scarcity. Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists. These areas could benefit by development of additional blue and green water, but human and financial capacity are limiting.
Blue	Abundant water resources relative to use: less than 25% of water flows from rivers is withdrawn fro human purposes.
Grey	Not assessed.

Figure 4.4 Area of physical and economic water scarcity. Source: Molden, 2007b.

Generally, a water availability below 2 000 m^3 per capita (pc) is considered low (regions in Asia and Africa) and less than 1 000 m^3 pc is catastrophically low (North Africa). From Table 4.1 it can be seen that in 1995 35% of the world population was living in areas with low water availability. It is expected that by 2025, 35% of the world population will be living in areas with a catastrophically low water availability.

In this analysis, the water requirements for environmental use and ecosystem services were not included. As mentioned above, in many river basins, only part of the potentially available water resources can be used. On average this is 60%, if environmental water requirements are taken into account. It is not clear whether this environmental water requirement is already taken into account in the 25% accessibility. Taking 25% as a reference for Table 4.1, this table and figure 4.4 show that in several areas maximum withdrawal has already been reached (basins in red and light red in figure above). This implies that the scope for expanding irrigation in these areas is limited. Improving water productivity of both blue and green water is the only way to increase production. It should be noted that the 25 and 60% are global averages that strongly vary among individual river basins.

Total water requirements and availability in river basins, including environmental water requirements (EWR), have been estimated by Smakthin et al. (2004), based on the WaterGAP 2 model (Alcamo et al., 2003). In their calculations, EWR to maintain a fair condition of freshwater systems range between 20 and 50% of the mean annual water flow. They expressed water demand and availability in a Water Stress Indicator (WSI), defined as the total actual water withdrawal as proportion of the maximum available runoff minus EWR. Table4.2 explains the meaning of the values of WSI. An overview of global WSI-values is given in Figure 4.5. This shows a similar picture to Figure 4.4, but with more detail and without economic water scarcity.

Table 4.2 Categorization of environmental water scarcity

WSI (proportion)	Degrees of Environmental Water Scarcity of River Basins
WSI > 1	Overexploited (current water use is tapping into EWR)— environmentally water scarce basins.
0.6 < WSI < 1	Heavily exploited (0 to 40% of the utilizable water is still available in a basin before EWR are in conflict with other uses) – environmentally water stressed basins.
0.3 < WSI < 0.6	Moderately exploited (40% to 70% of the utilizable water is still available in a basin before EWR are in conflict with other uses).
WSI < 0.3	Slightly exploited

Notes: WSI= Water stress indicator; EWR= Environmental water requirements.

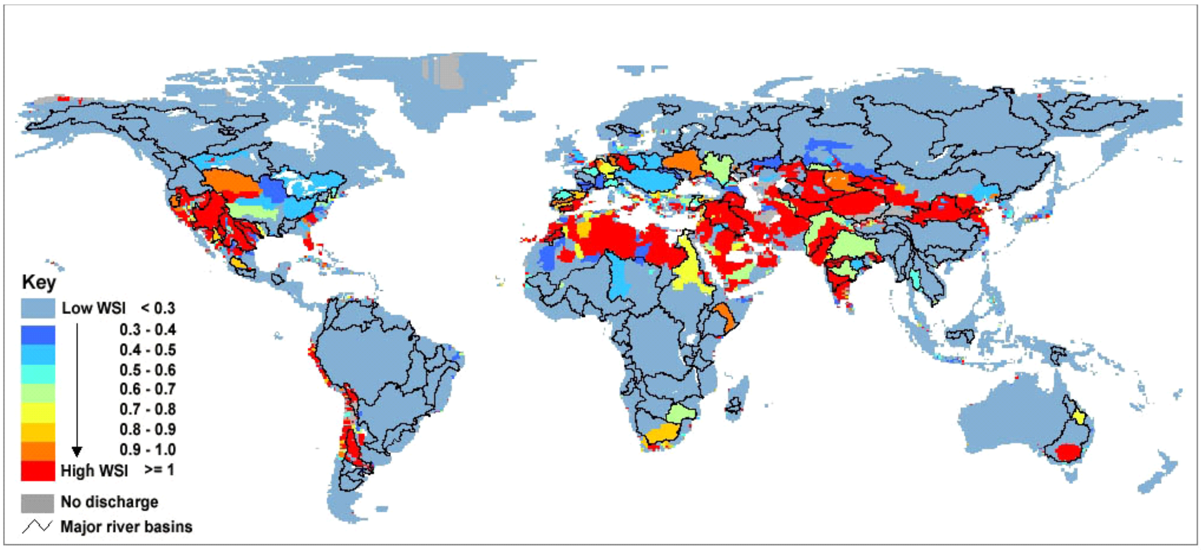


Figure 4.5 A map of the water stress indicator taking into account EWR. Source: Smakthin et al., 2004.

A drawback of this analysis for some highly industrialised countries is that industrial water use can disturb the picture. For instance in the Netherlands and Germany WSI is high, probably because large amounts of water are used for cooling in industry. This water is largely recycled. Based on this info, it would be wrong to conclude that there is no scope for energy crops.

4.7 Trends in water use

The information presented in this section is largely based on the following sources: Shiklomanov (2000), Berndes (2002), Molden et al. (2007), Vőrősmarty et al. (2000). Only if other sources are used, they are mentioned explicitly.

4.7.1 Trends in water use in the domestic and industrial sectors

Several studies explore trends for future water withdrawal and use by the three sectors domestic, industry and agriculture. The waterGAP-model (Alcamo et al., 2003) takes into account structural and technological changes in its calculations, referring to changes related to development, economy and life-style and those related to technological improvements. The result of their assumptions is that in the period to 2025 global water withdrawal by the industrial and domestic sectors will hardly change. In industrialised countries, water withdrawal tends to decrease due to saturation of domestic water use and technological improvements in industrial water use (e.g. more recycling), the amount depending on the scenario selected. In developing countries, water withdrawal will hardly change as increasing withdrawals will be offset by better utilization.

Shiklomanov (2000) expects domestic water use to increase by 75% and industrial water use by 55%. He has taken account of UN forecasts and industrial development forecasts, as much as possible per country. However, this accounts for roughly 30% of the water withdrawals in both cases. In developing economies, such as Brazil, India and China it is expected that domestic water use will increase to the level of that in industrialized regions (Figure 4.1). Predictions and trends strongly depend on the assumptions and selected scenarios.

Fraiture et al. (2007) foresee an increase in blue water withdrawals for non-agricultural sectors by a factor of 2.2 by 2050. They project that water withdrawals for domestic use will increase from 278 km^3 in 2000 to 681 km^3 in 2050, a 245% increase, while industrial withdrawals will increase by 250% (from 245 km^3 in 2000 to 617 km^3 in 2050).This will result in stronger competition for water, and will result in water being less water available for irrigated agriculture in already water-stressed areas. However, the largest part of water withdrawn for non-agricultural purposes (75%-85%) is not consumed, but flows back to rivers, lakes or groundwater. In (peri-)urban areas, this waste water can be used in high-value vegetable cultivation, provided it is clean enough. Especially in water-scarce areas, this is a valuable contribution to increasing water productivity.

4.7.2 Trends in agricultural water use

Agricultural water use will continue to increase, but less than the population. The developments will depend very much on expansion of irrigation and changing diets. A vegetarian diet requires 2000 kg water per capita per day and a grain-beef diet requires 5000 kg. In the year 2000, total evapotranspiration for food and feed production was 7130 km^3 for 6.1 billion people, which implies an average use of 3200 kg water per capita per day. As shown, globally large regional differences in water availability and water use exist, in some regions leading to water stress while in other regions water is abundantly available.

Fraiture et al. (2007) indicate that if present trends are extrapolated, without improvements in land and water productivity or major shifts in production patterns, water use in agriculture will increase by 70-90% until 2050, depending on actual population and economic developments. This projection does not include water needed for biomass production for biofuels. It implies that evapotranspiration will increase to 12,050 – 13,500 km^3. This includes evapotranspiration from rice paddies, irrigation and reservoirs, but does not account for evaporation from grasslands and aquaculture.

Using a combination of strategies, Molden et al. (2007) present an “optimistic” scenario for 2050 that assumes that serious investments will be made in improving water management in agriculture. This scenario is built on strategies that vary among regions, and concludes that rainfed cereal yields increase by 35-60% and crop WP increases by 25-35%. For irrigated crops, these values are 40-60% and 30-40%, respectively. The area under arable crops is expanded by about 15% at global scale, and so is the irrigated area. This implies that much of the increase in production is associated with intensification of agriculture. Water depletion is expected to increase by 18% and water withdrawal by agriculture by 21% (from 2600 to 3190 km^3) Some of this increase will be compensated by increases in water productivity and water use efficiency. However, even in the most optimistic scenario, agricultural water withdrawals increase (Fraiture et al., 2007). This scenario also does not include energy crops.

4.8 Field and Farm scale

4.8.1 Irrigation systems

Some typical values of irrigation efficiency for different irrigation systems are presented in Table 4.3. These efficiencies relate to the classical definition of irrigation efficiency: net evapotranspiration (i.e. evapotranspiration minus precipitation) as proportion of the amount of water diverted to the irrigation system (Seckler et al, 2003). As explained extensively, the complement cannot be considered lost but will at least partly be available elsewhere in the system. One should consider these as part of the river basin. Increasing crop water productivity and water productivity at the river basin scale is what is finally aimed at.

Table 4.3 Classical irrigation efficiency of irrigation systems

Irrigation system	Irrigation efficiency
Conventional gravity	30-50% (paddy irrigation to flooded fields)
Level basin	40-70% (high value with laser beam levelling)
Sprinkler	60-75%
Drip	80-90%

Source: Seckler et al, 2003

4.8.2 Water Use Efficiency of crops

Water use by crops can be calculated on a daily basis by simulation based on weather data and crop growth (Wolf et al., 2003). Evapotranspiration can be calculated based on processes governing stomatal conductance and vapour pressure deficit between stomata and the outside air. However, a more applicable unit in this type of studies is a crop specific WUE.

WUE can be expressed both in terms of total evapotranspiration (ET), including non-productive soil evaporation, or in terms of crop transpiration (T). Evaporation does not contribute to crop yield, but refers to water loss directly from the soil surface. Permanent crops cover the soil more or less completely during the whole year and therefore evaporation is relatively low. Crops that are sown annually need time to germinate and cover the soil, during which period evaporation is substantial, the actual amount depending on weather conditions.

WUE is variable, because of variations in crop characteristics (especially the difference between C_3 and C_4 crops and weather conditions. Generally, WUE and water productivity of C_3 crops are lower than those of C_4 crops, because of the difference in photosynthetic mechanism; high temperatures, or rather low atmospheric humidity conditions, lead to high E and high T losses (Tanner & Sinclair, 1983; de Wit, 1958).

When expressed in terms of ET, the variability increases, because rainfall pattern and crop management also affect the magnitude of losses through soil evaporation. Many small showers, resulting in extended periods of soil wetness and shallow wetting, lead to higher E losses than a few large ones, which results in more infiltration and a larger fraction of infiltration being available for crop transpiration. Also crop growth under nutrient-deficient conditions leads to longer periods of incomplete soil cover (growth rates are lower), and hence to higher evaporative losses (Penning de Vries & Djitèye, 1982).

WUE based on transpiration (WUE_t) is thus less variable, as the influence of non-productive evaporation is excluded. If expressed in g DM produced per kg water transpired, typical values for C_3 crops are 2-3 and for C_4-crops 3.5-4.5.(Van Keulen & Van Laar, 1986)

A high WUE can only be achieved if other factors (nutrient availability, incidence of pests and diseases, appropriate and timely management) are not limiting crop production. Management can reduce WUE drastically (Bessembinder et al., 2003). If nutrients are limiting, the water can simply not be used to produce biomass, while evaporative losses are also much higher, because soil cover is lower. Pests and disease reduce production, while water use remains the same. Soil tillage and/or late sowing result in increased losses by evaporation, leaving less water for the crop.

Hence, in different regions of the world large variations in actual WUE are found. It should be noted that the water source is not included in the WUE. It just applies to crop water use.
Measures to increase the ‘productive efficiency’ of water use are for instance reduction of the soil evaporation component, through ‘better’ timing of crop growth, or through stimulation of crop closure through application of nutrients and prevention of pests and diseases.

If water is the major factor limiting crop production, total water use can be calculated by multiplying crop yield and WUE_t. Or the other way around: if the amount of water available is known, yield can be calculated from WUE_t.

For a wide variety of crops, water use efficiencies have been compiled, based on different sources (Table 4.4). The data in the FAO study refer to averages of FAO-irrigation projects at field scale and hence refer to evapotranspiration (ET). However, management is not indicated. Generally, these fields will have been looked after quite well (sufficient weeding, nutrient application, timely management).
This implies that the figures indicate a WUE that can be achieved under ‘good management’. The Table shows that data are not fully consistent. Sugarcane has a high WUE, because it is a C_4 crop, has a long growing season, is a permanent crop and has a high growth rate. Evaporation from soil is negligible, while other crops have to be sown and evaporation is a substantial part of total water use. The high yield of sugarcane can only be achieved under optimal conditions and a closed crop canopy (radiation, temperature, nutrients, no pests and diseases).

The part of the crop used for bio-energy varies strongly among crops, so WUE for total crop dry matter production does not necessarily indicate the water use efficiency for energy production. In addition, some crop residues can be processed for heat or electricity (bagasse from sugarcane). Hence, allocation of water use to multiple (by)products is a point of discussion that cannot be overlooked when assessing WUE.

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. Considering only the potentials is too simplistic. This would favour assessment of water use in relation to the different crop production systems as distinguished in the chapter on Food demand. A suggestion to make WUE a meaningful parameter in assessing water availability for energy crops, is to distinguish between three levels: a low – medium – high WUE related to a low – medium – high input use, such as nutrients, pesticides and management in general.

Table 4.4 WUE for some energy crops according to different sources.

Data compiled by Berndes are based on different sources and also refer to ET. Data from Penning de Vries refer to transpiration.

	growing period short	growing period long	water req growing period	water req growing period	highest product yield trop	highest product yield subtrop	Highest product yield temp	Harvest Index DM basis	biomass trop	biomass subtrop	biomass temperate	g product DM /kg water	g product DM /kg water	g biomass DM/kg water	g biomass DM/kg water	Mean water req
Crop	days	days	mm	mm	DM ton/ha	DM ton/ha	DM ton/ha		DM ton/ha	DM ton/ha	DM ton/ha	low WUE	high WUE	low WUE	high WUE	mm/d
FAO-IDP33																
maize	100	140	500	800	7.92	8.80	5.28	0.4	19.8	22.0	13.2	0.70	1.41	1.76	3.52	5.4
potato	100	150	500	700	5.40	9.45	10.80	0.6	9.0	15.8	18.0	1.08	1.89	1.80	3.15	4.8
sorghum	100	140	450	650	4.35	4.35	2.61	0.35	12.4	12.4	7.5	0.52	0.87	1.49	2.49	4.6
soybean	100	130	450	700	3.22	3.22		0.35	9.2	9.2		0.37	0.64	1.05	1.84	4.9
sugarbeet	160	200	550	750		10.20	9.35	0.4		25.5	23.4	1.02	1.53	2.55	3.83	3.6
sugarcane	270	365	1500	2500	30.00	28.00		0.25	120.0	112.0		1.00	1.60	4.00	6.40	6.2
sunflower	90	130	600	1000	3.22	3.22	2.30	0.25	12.9	12.9	9.2	0.28	0.46	1.10	1.84	7.2
wheat	100	130	450	650	5.16	5.16	5.16	0.4	12.9	12.9	12.9	0.69	0.86	1.72	2.15	4.8
Berndes (2002)																
rape seed												0.9	1.2			
sugarcane												1.7	3.3			
sugarbeet												0.9	2.4			
corn												0.7	2.1			
wheat												0.6	3.6			
lignocellulose crops[1]												1.0	9.5			
Clifton-Brown, 2000																
Miscanthus[2]												4.1	22			
Pening de Vries, 1982 [3]					Actual yield				Actual yield							
Natural vegetation	40				1.4			1	1.4						3.5	1.0
Nat.veg. fertilized, sand	40				5			1	5						4.7	2.6
Nat.veg. fertilised, clay	40				9.5			1	9.5						5.9	4.0

1 includes Miscanthus, has a high value (9.5)

2 pot experiment

3 refers to Transpiration only (not ET), in Sahel

4.9 Alleviating water stress

All studies suggest solutions or directives for improving water use efficiency at specific scales. It is generally acknowledged that substantial improvements are possible. As water is a scarce resource in many regions, especially in those with semi-arid climates, the scope for energy crops will widen, if water availability increases. Below is a short list of the various measures mentioned:

All sectors
- Decrease use in industries
- Better utilization of local water
- More recycling of industrial and domestic water
- Use of static water (ice)
- Redistribution between territories
- Water conservation
- Change diets towards less water consuming foods (less meat, or chicken and pork instead of beef)
- Agricultural trade: produce at locations where water is available and then transport products (virtual water)

For agriculture many measures to improve water productivity can be identified that differ for rainfed and irrigated agriculture.
Rainfed:
- improve water productivity by water harvesting, better management of soil moisture and supplemental irrigation (better utilization of green water)
- expand area

Irrigated:
- in irrigation: use clean waste water, groundwater, storage
- improve water productivity, integrate livestock and fisheries
- better maintenance of irrigation systems
- better regulation of water distribution

General:
- decrease gap between actual and potential yield by optimizing crop management (nutrient availability), and reducing post-harvest losses, processing losses, losses due to pests, diseases and weeds. This leads to higher production without increasing water use.

Although it seems easy to improve WP, it should be noted that in regions with high yields, these measures have already been taken. In low-yielding regions, the scope exists but it should be noted that improvements at field scale should be evaluated at river basin/regional scale.

4.10 Climate change

Many climate models have been developed over the years. They all agree that the average global precipitation will increase with time as the hydrological cycle is enhanced by global warming. Most models indicate an increasing variability of rainfall patterns and increasing amount of heavy rainfall events. Predicted temperature changes by these models are uncertain, but the predicted rainfall changes are even more uncertain. They agree about the order of magnitude of the change but differ on the spatial pattern. Hence, for specific regions predictions may vary substantially. An example is given in Figure 4.6. It indicates the expected relative changes in annual average precipitation as calculated by several models in the IPCC assessments for the emission scenario A1B. The 20-year average of 1980-1999 is compared to the 10-year average of 2090-2099. The left-side map represents the period December – February and the right map the period June – August. For the white areas less that 66% of the models agree in the sign of precipitation change. The stippled areas indicate the areas in which more than 90% of the models agree in the sign of the change. In some areas expected changes are as high as 20%.

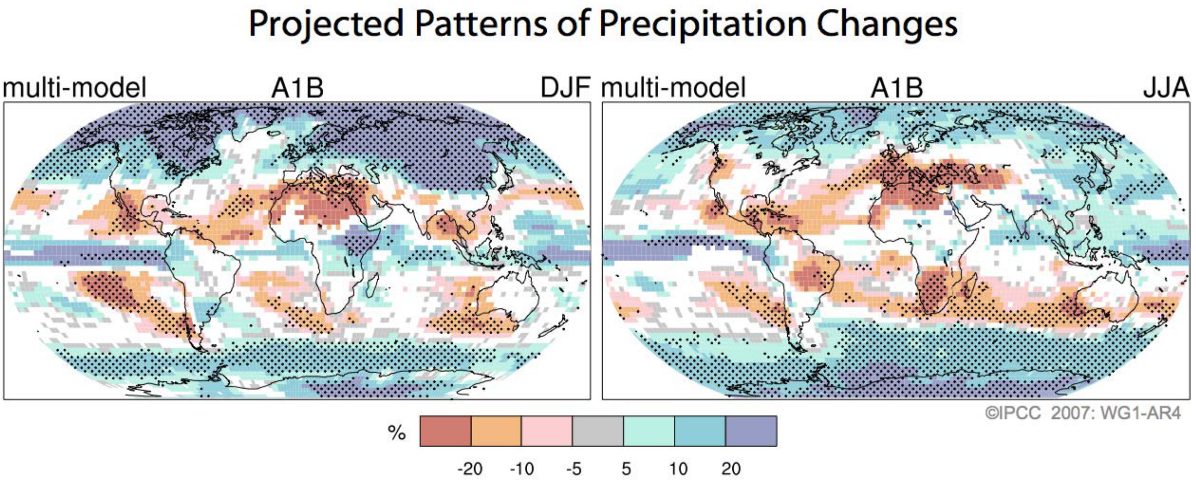


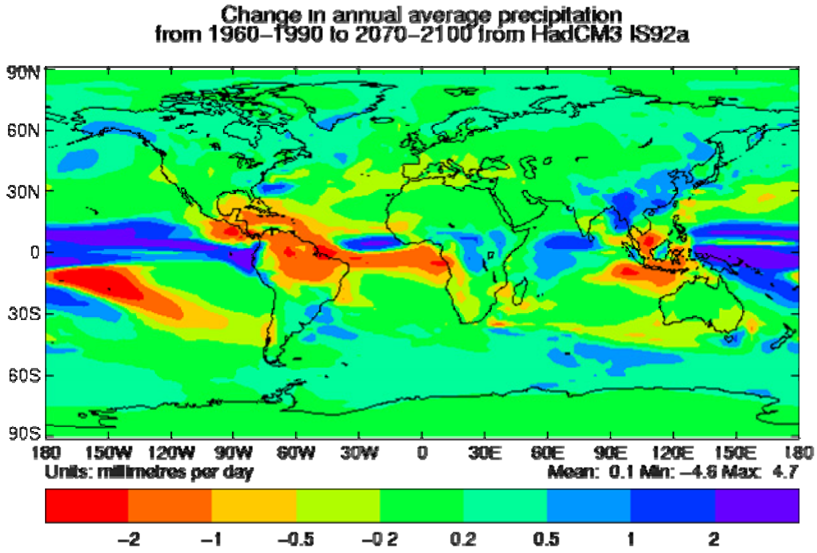
Figure 4.6 Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999.

Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. SOURCE: IPCC, 2007.

Another example of changes in precipitation predictions is given in Figure 4.7. It indicates the absolute mean annual changes in mm per day according to Climate Model 3 of the Hadley Centre (Hadley, Centre, 2005), one of the models used in the IPCC Assessment.

In general, it is agreed that the amount of precipitation is expected to increase in high latitude areas, and to decrease in most sub-tropical land areas. Rainfall variability is expected to increase. Moreover, the incidence of extreme weather events, including rainfall is expected to increase (IPCC, 2007, Hadley Centre, 2005). IPCC (2007) expects that the average river run-off and water availability will increase by 10-40% at high latitudes and in some wet tropical areas and decrease by 10-30% in some dry regions, mid latitudes and dry tropics. Some of these areas are already water stressed. Due to increasing temperatures water presently stored in ice will melt, on the long term diminishing water availability in areas depending primarily on melt water

Of course, this has large consequences for agricultural practices, especially when also temperature changes are taken into account. For assessing the possibilities for energy crops these influences of climate change on agricultural production have to be taken into account, although will be accompanied with large uncertainties.



dley Centre for Climate Prediction and Research, The Met. Office

Figure 4.7 Changes in annual average precipitation form the period 2070–2100, relative to 1960–1990 (Source: Hadley Centre: http://www.metoffice.gov.uk/research/hadleycentre/models/modeldata/HadCM2_IS92a_map_P_MAM_196 01990_20702100.gif)

4.11 Conclusions

The major water consumption in biofuel production is associated with crop production and not with processing. Fresh biomass contains water that is lost during processing. However, this is generally less than 2% of the amount involved in crop growth (Berndes, 2002).

Most studies observe a relation between poverty, hunger and water stress, leading to problems especially in arid, semi-arid sub-humid climates. Comparing the different analyses and suggested solutions shows that problems are analysed at a higher scale than the solutions are formulated. The large variability in regional climate and hydrology asks for more detailed and local analyses of the biophysical possibilities for crop production. The studies analysed show that in some regions water is abundant, providing ample opportunities for energy crops. However, in regions with water scarcity, these opportunities appear to be absent, at least at rather large scale.

A major point of discussion is that improvements in water productivity at field/plot scale cannot be extrapolated indiscriminately to higher scale, because we have a situation where 'water losses' upstream are available for use downstream; so that when efficiency of water use upstream increases, there may be less water available downstream. To estimate water availability for energy crop production it is best to execute the following steps:

- Exclude the areas with a water stress indicator above 0.6
- estimate renewable water resources at the scale of a 'river basin' area
- determine how much water is being used in food crop production, and add projections for the future. Use WUE for food and feed crops related to input levels of the production systems
- estimate the available land area for additional crop production
- assess 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 at the larger regional scale and vice versa. It does not require straightforward aggregation, but more detailed analyses of relations to arrive at an optimal water distribution.

The local situation should be analysed to assess the scope for energy production. However, until now, studies at this level of resolution have not been executed, and global figures give a misleading picture. Hence, in providing a rough indication of the amount of blue and green water available for energy crop production, it is necessary to be very cautious. The studies reviewed in this assessment and the numbers mentioned above, present the following picture for blue water:

Accessible blue water: 12,500 km^3
Environmental water requirements: 20 to 50% of accessible water, i.e. 2,500 km^3 to 6,250 km^3
Current blue water withdrawals for irrigation: 2,605 km^3
Current blue water depletion in irrigation: 1,570 km^3
Projected trends in water depletion for food and feed production to 2050: 90% increase if no major investments, i.e. 2983 km^3
Other blue water withdrawals: very unclear picture, around 902 km^3 in 2000, projected 1963 km^3 in 2050. Level of depletion unknown.
Total water depletion in 2050: 4,946 km^3
Apparent blue water availability for energy crop production: 5,054 km^3 if 20% EWR, 1,304 km^3 if 50% EWR.

This very rough estimate indicates an estimated range in blue water availability for energy crop production, depending on the level of environmental water requirements chosen. However, whether this water is available in river basins in which also suitable land is available cannot be determined based on available studies.

The scope for energy crops should be analysed at different scales, as shown in the previous sections i) the field/farm scale and ii) the regional/river basin scale. The challenge in this type of studies is to link WUE at field or farm scale to water availability at river basin scale.
If one favours improvements of actual yields and management systems, one should be very careful to consider how realistic this is. Often agricultural products do not yield enough financially to justify investments. Here may be a role for energy crops, provided they do yield substantially more than food and feed crops.

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5 Biodiversity

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5.1 Introduction

Large scale production of biomass for bioenergy purposes will undoubtedly have consequences for biodiversity. However, there is controversy about the nature and magnitude of these impacts. Clarifying the controversy (for instance by defining conditions and assumptions for the different outcomes) is an important contribution to this WAB study.

The first question is: what exactly do we mean with biodiversity? How is it related to concepts of ecological value or nature? There are many definitions and indicators. Therefore an overview is given in 5.2.

The impacts on biodiversity can be assessed at different levels:

- Locally: mainly the impact of land-use changes
- At the level of the production-consumption chain: comparison of LCA's of different biofuels with fossil fuels as a reference, but another reference could be another application of the same biomass
- Globally: the impact of the implementation of new, additional biofuel systems compared to a situation (scenario) with the current level of implementation of biofuels
- Globally: the impact of a future system including biofuels, but including other changes like agricultural productivity and dietary patterns as well (scenarios; model assessments) compared to the present level of biodiversity.

The local level can be of interest in case of regional or national biodiversity goals. In the present situation most of the international agreements and guidelines set goals on the national level.
The level of the production-consumption chain is recognized in criteria for specific biofuels (i.e. reduction of greenhouse gas emissions on this level). These criteria might be applied as guidelines in national or European policies. The global level is most relevant for strategic options. On this level discussions are about the sustainability of biofuels in general, in many cases with distinction between first and second generation of biofuels. In screening existing studies on the (potential) effects of biofuels on biodiversity, it is important to distinguish between these levels.

In all cases the impact assessment on biodiversity requires a lot of fundamental knowledge, which is not (yet) available on most of the aspects without major uncertainties. Important issues are the effect of climate change on biodiversity, the availability of land with certain characteristics and the productivity of biomass cultivation and the ecological value of different land-use options. In table 5.1 the most important knowledge issues are summarized.

Besides more independence of fossil oil and gas and new agricultural markets a strong motivation for bio-energy production is the reduction of fossil fuel use. An important result is the reduction of greenhouse gas emissions. This reduction will result in mitigation of climate change. The effect of climate change mitigation implies a positive contribution to the reduction of future global biodiversity loss, but it is not easy to quantify this effect. The associated trade-off is increased land-use for production. Much debate is presently going on about the availability and suitability of (recently) abandoned and/or degraded agricultural areas for bio-energy production. The availability of suitable existing agricultural land would reduce the pressure on natural grasslands and forests and could therefore limit the additional conversion of natural ecosystems.

A survey of the main issues and more detailed aspects of these issues in presented in table 5.1. Local emissions of industrial processes and the burning of the biofuels are expected only to have a minor impact on biodiversity and are not discussed in this report.

Table 5.1 Main knowledge issues in the impact assessment of biofuels on biodiversity

Main issue	**More detailed aspects**
The allocation of bio-energy production and the associated land-use changes	Productivity (energy per hectare) related to soil characteristics (natural or degraded) and climate characteristics (and climate change) Availability of land with specific characteristics (present situation and future situation based on scenarios) Impact on carbon content of the soil
The biodiversity value of land used for the cultivation of energy crops	Present biodiversity values of available land Potential future biodiversity value, if the land is not used for bio-energy production
The local/regional environmental impact of the cultivation of energy crops	In general: productivity related to the management (fertilizer use, irrigation) and more specific: Acidification Eutrophication Effects of pesticides Water use Risks of GMO New infrastructure (ecological barriers)
The expected effect of (reduced) climate change on biodiversity	GHG emission reduction in the production-consumption chain (compared to a reference) GHG-emissions related to the increase of temperature in time Increase of temperature in time related to impact on specific ecosystems (terrestrial and aquatic) Large scale effects (sea level rise, El Nino) in time and the ecological impacts
The local/regional environmental impact of the processing of the biomass and the application of the biofuels	Acidification Fine dust

5.2 Biodiversity definition, policies and indicators

5.2.1 Relevancy to policy makers

Policy targets on biodiversity
The loss of biodiversity (the loss of organisms, communities and even entire ecosystems) is a global concern that has led to the adoption of biodiversity conservation targets in several environmental conventions under the UN. The main conventions are the Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD).

The ultimate, long-term, goal of climate change policies is formulated as "*stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*" (UNFCCC, 1992). Consequences should be prevented, for instance on flooding risks, food supply and biodiversity. To reach this ultimate goal, a more operational target has been formulated: limiting global temperature rise to 2 degrees above pre-industrial levels by 2100. Further derived targets are limiting sea level rise to a maximum of 50 cm, and limiting the rate of temperature rise to 0,1 degree per decennium.

The 2-degree target is also taken up in European and Dutch climate policies (EC, 2004; VROM, 1991).
The Strategic Plan of the CBD convention (UNEP, 2004) contains a short term goal, the so-called 2010 target "*to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth*". This goal was subsequently adopted by the World Summit on Sustainable Development, and was reconfirmed at the 2005 World Summit of the UN. Several policy targets at more regional or national levels are derived from and in line with these global goals, and are translated into action plans (see also par 5.2.6). One of the derived targets is to protect 10% of the surface of each distinguished ecoregion. In the Netherlands, the different policy actions taken by several Ministries are compiled in a broad program called the International Biodiversity Program BBI (Ministery of Agriculture Nature and Fisheries, 2003).

Relevant for the subject of biofuels, is the notion that there are both concrete short term (2010) and more general long term (2100) biodiversity targets under different conventions. Measures that can be applied for the short term CBD target can be very diverse, counteracting the effects of land-use change, fragmentation, infrastructure, N-deposition, pollution, climate change, etc. For the long term climate change goals, most measures (one of which is bio-energy production) are targeted at reducing greenhouse gas emissions, next to adaptation measures like increasing landscape connectivity and expanding the suitable habitats for species to survive climatic changes.

Indicators necessary for policy decisions and interventions
An important issue for effective policy support is therefore the development of a small number of simple biodiversity indicators that adequately express the status and trends in biodiversity. As a former Dutch Minister of Public Works and Water management once stated: "no figures, no policy". In The Hague 2002, the member states agreed to significantly reduce the rate of loss by 2010 at the global, regional and national level. Shortly afterwards the European Union and pan-Europe agreed upon a halt of the loss of biodiversity by 2010 ("ministerial process Environment for Europe", Kiev, 2003). In May 2004 the 'Message of Malahide' listed a first set of European Biodiversity Headline indicators to evaluate the progress towards the 2010-target at the European level similar to the above listed CBD indicators. The European Council urged the European Commission to develop, test and finalise this set by 2006. The use of similar indicators at the global, regional and national level is recommended by the CBD for efficiency and consistency reasons. Since 1997 the Dutch government has actively contributed to consistent global and regional indicator development in the CBD, OECD and Europe.
To understand observed changes in biodiversity, the influence of environmental pressures must be known from detailed research. With this knowledge, biodiversity change can be modelled. Such models can be applied in future projections of global environmental change. These projections are constructed in the context of policy interventions, and must show the effects both on the short (5-10 years) and long term (50-100 years) to show possible synergies, counteractions and trade-offs in space and time. The main questions of policy makers that should be addressed by an effective indicator system (see figure below) can be summarized as:

1. What is changing (indicator)?
2. Why is it changing (drivers)?
3. Why is it important (human use)?
4. What can be done about it (policy options and measures)?

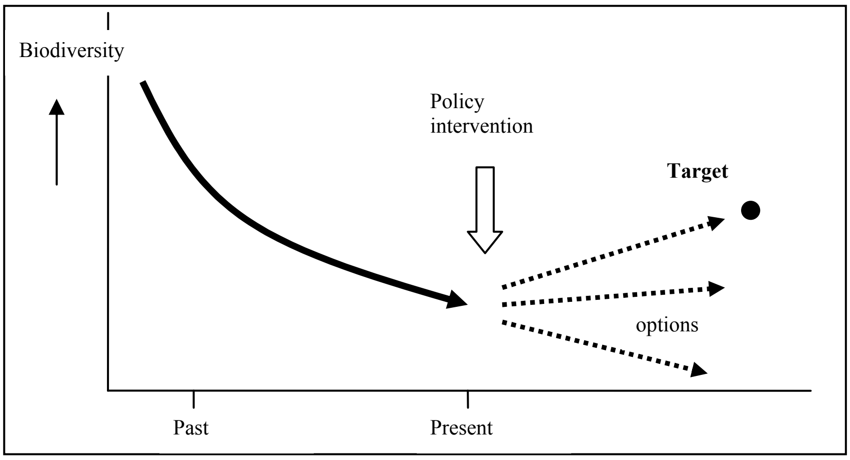


Figure 5.1 The basic elements of a policy relevant indicator: setting verifiable targets, up-to-date monitoring system, and availability of options or measures to achieve corrections on the trend.

5.2.2 Biodiversity definitions and indicators

Biodiversity is the contraction of two words "biological" and "diversity". Biodiversity is not only the sum of all ecosystems, species and genetic material. Rather, it represents the variability within and among them. It is a therefore a complex phenomenon that can be defined and dealt with in many different ways. The Convention on Biological Diversity gives a formal definition of biodiversity in its Article 2: "biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (http://www.cbd.int/convention/convention.shtml). Biodiversity encompasses the overall variety found in the living world and includes the variation in genes, populations, species and ecosystems. It refers to all life forms that can be found on Earth (plants, animals, fungi and micro-organisms) as well as to the communities that they form and the habitats in which they live. Biological diversity is often understood at three levels:

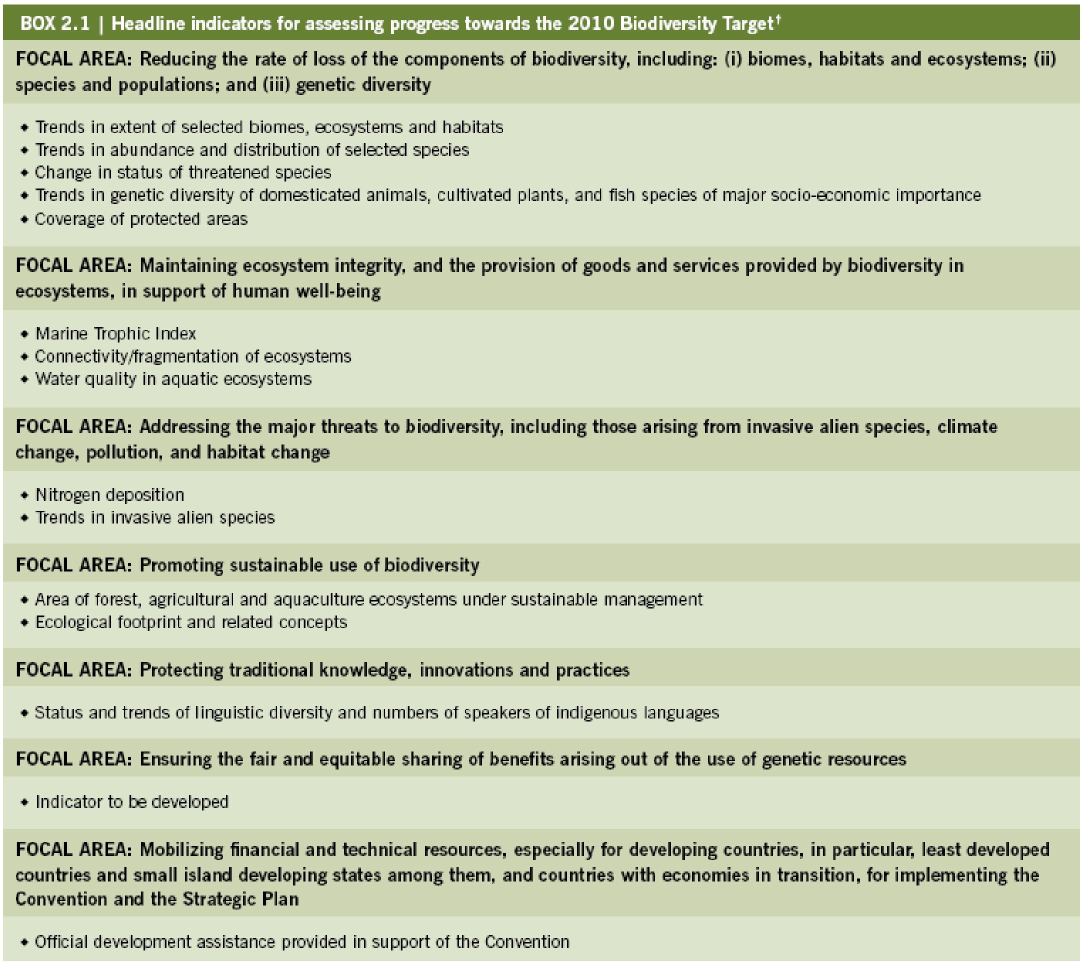
- Species diversity refers to the variety of different species (plants, animals, fungi and micro-organisms) such as palm trees, elephants or bacteria;
- Genetic diversity corresponds to the variety of genes contained in plants, animals, fungi and micro-organisms. It occurs within a species as well as between species. For example, poodles, German shepherds and golden retrievers are all dogs, but they all look different;
- Ecosystem diversity refers to all the different habitats - or places - that exist, like tropical or temperate forests, hot and cold deserts, wetlands, rivers, mountains, coral reefs, etc. Each ecosystem corresponds to a series of complex relationships between biotic (living) components such as plants and animals and abiotic (non-living) components which include sunlight, air, water, minerals and nutrients.

These three levels can be summarized as genetic, species and community diversity, and different indicators have been listed for these levels (Reid *et al.*, 1993).

In selecting appropriate biodiversity indicators for policy support, several criteria must be met (Scholes & Biggs, 2005; Spangenberg, 2007; ten Brink, 2007):

- Supplied information is relevant for agreed policy agendas (such as CBD 2010 target)
- Information is simplified and easy to understand, to communicate complex phenomena
- Information is quantified, relative to a clearly defined reference situation
- Indicator is scientifically sound
- The indicator status can be monitored and explained
- Indicator can be related to human impacts (environmental pressures)
- It can be modelled and used to show historical and future developments
- It is sensitive to policy actions
- It can show possible trade-offs in time and space, and identify conflicting goals

Table 5.2 CBD Headline indicators



BOX 2.1 | Headline indicators for assessing progress towards the 2010 Biodiversity Target†

FOCAL AREA: Reducing the rate of loss of the components of biodiversity, including: (i) biomes, habitats and ecosystems; (ii) species and populations; and (iii) genetic diversity

- Trends in extent of selected biomes, ecosystems and habitats
- Trends in abundance and distribution of selected species
- Change in status of threatened species
- Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance
- Coverage of protected areas

FOCAL AREA: Maintaining ecosystem integrity, and the provision of goods and services provided by biodiversity in ecosystems, in support of human well-being

- Marine Trophic Index
- Connectivity/fragmentation of ecosystems
- Water quality in aquatic ecosystems

FOCAL AREA: Addressing the major threats to biodiversity, including those arising from invasive alien species, climate change, pollution, and habitat change

- Nitrogen deposition
- Trends in invasive alien species

FOCAL AREA: Promoting sustainable use of biodiversity

- Area of forest, agricultural and aquaculture ecosystems under sustainable management
- Ecological footprint and related concepts

FOCAL AREA: Protecting traditional knowledge, innovations and practices

- Status and trends of linguistic diversity and numbers of speakers of indigenous languages

FOCAL AREA: Ensuring the fair and equitable sharing of benefits arising out of the use of genetic resources

- Indicator to be developed

FOCAL AREA: Mobilizing financial and technical resources, especially for developing countries, in particular, least developed countries and small island developing states among them, and countries with economies in transition, for implementing the Convention and the Strategic Plan

- Official development assistance provided in support of the Convention

To translate scientific data into policy relevant information, it is inevitable that detailed data is summarized in easy to understand overall indices. Several complementary indices are used within the CBD framework as there is no single indicator available that will cover all important aspects and issues, and is sensitive to all pressures and interventions.

In 2004 a global agreement was achieved on a small number of indicators (see Table 5.2) in order to review the progress towards the 2010-target and guide policy makers in finding effective measures (UNEP, 2004). The indicators are related to main subjects as: status and trends in components of biodiversity, biodiversity threats, sustainable use, and ecosystem goods and services. Five specific global indicators have been selected on the state of biodiversity to evaluate the progress towards the 2010-target, for immediate testing:

- Trends in extent of selected biomes, ecosystems and habitats;
- Trends in abundance and distribution of selected species;
- Change in status of threatened species;
- Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance;
- Coverage of protected area.

Much debate is ongoing on the use of single or composite indicators: scientists want detailed accuracy and policy makers want simplified headlines. In aggregating information, you can think of a sort of “information pyramid”, with raw field data at the base, statistics and single indicators in the middle, and composite indicators at the top. Raw data are variables measured in the field. Statistics are aggregations of these data over space and time (e.g. population trends). Single indicators are such statistics related to a reference value (e.g. number of storks compared to viable population). A reference or baseline might be a target, a threshold value, or a reference year. Composite indicators are produced by aggregating various single indicators. Single indicators can be transformed into dimensionless indices by dividing them by a reference value (e.g. average population size of 10 species as % of undisturbed state). Another approach is the weighted transformation into a common unit (e.g. methane and CO2 emissions transform into greenhouse gas equivalents). Both calculation procedures aim at data compression and the transformation of data into meaningful information. The level of aggregation depends on the user needs. Site managers are usually interested in statistics and single indicators, while politicians are mostly interested in composite indicators.

5.2.3 Biodiversity loss and the homogenisation process

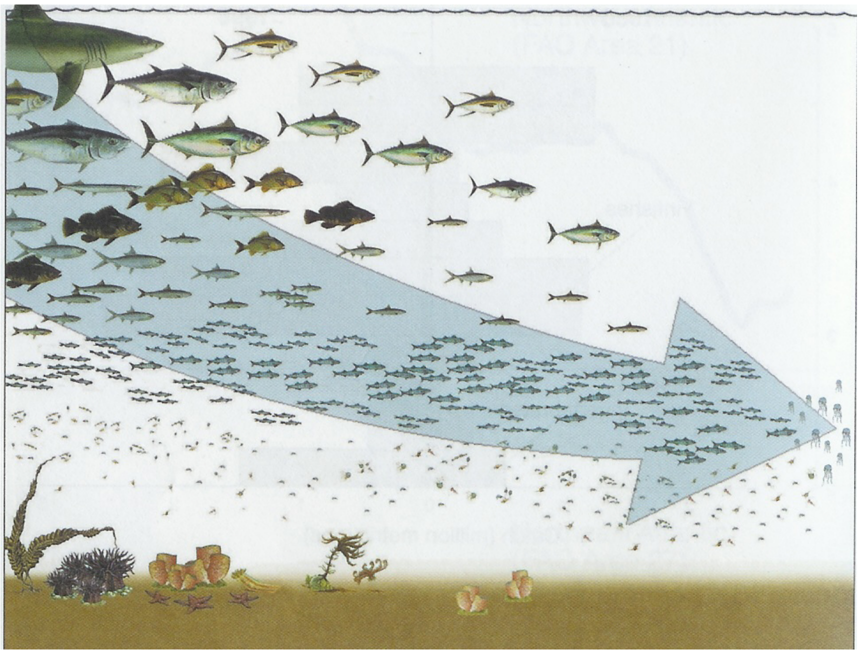


Figure 5.2 "Fishing down the food web (Pauly et al., 1998) A graphical representation of the homogenisation process in the marine environment.

Biodiversity loss consists of loss of natural area, changes in species abundance in the remaining area and species extinction (locally or globally). Changes in species distribution are generally characterised by a decline in the abundance (=number of individuals or population size) of many original species, combined with an increase in the abundance of a few other - opportunistic and widespread - species as a result of human activities. Species extinction is the last step in a long degradation process. Repeated local extinctions ('extirpation') precede the potentially final global extinction. As a result, different ecosystem types are becoming more and more alike, which is referred to as the homogenisation process (McKinney & Lockwood, 1999; Myers & Worm, 2003; Pauly *et al.*, 1998; Scholes & Biggs, 2005; ten Brink, 2000). Decreasing populations are as much a signal of biodiversity loss as highly increasing species, which can sometimes lead to plagues in terms of invasions and infestations. Figure 5.2 shows the homogenisation process from left to right.

Much research has focused on the reasons of the increased biodiversity loss in the 20th century. Identified anthropogenic drivers influencing the loss of biodiversity are land conversion and land-use change, fragmentation, pollution, eutrophication, climate change and the introduction of invasive species (Sala, 2000). Although climate change is a gradual process, several studies concluded that climate change is already affecting species distributions all over the world and will impact nature to a considerable amount in the 21st century.

As homogenization is brought about by different pressures, it can serve as a general concept for biodiversity modelling, and this has been done in the GLOBIO 3 model. As such, the process of habitat fragmentation is a part of this approach, and knowledge on this important driver of biodiversity loss is incorporated (ten Brink & et al., in prep.).

5.2.4 Suitability of species richness as an indicator for impact assessment

At the global level the number of species is decreasing following (recent) extinction (Hassan *et al.*, 2005). Extinction rates over the last 100 years are about 100 times higher than rates for comparable species found in the fossil record. The observed changes in species numbers have raised political interest in biodiversity loss. In the scientific arena, most attention has focused on studying biodiversity in terms of the number of species at a place. A commonly used indicator for indicating the biodiversity status and historical trend is therefore **species richness**. Taking the spatial dimension into account leads to different levels of biodiversity, generally called α, β and γ diversity. This group of terms differentiates between local species richness (α diversity, the number of species at a location), the regional species pool (γ diversity, the number of different species that potentially occur at a location) and the variability between localities (β diversity), which relates to the regional landscape structure and the mosaic of different natural ecosystems and land-use types. Biodiversity is declining mainly on two scales: β-diversity decreases as species identities are becoming more similar in different locations (homogenization), and γ diversity decreases as species become globally extinct (Thompson & Starzomski, 2007). There are several arguments that for the limited use of absolute numbers of species (indicator species richness) in local and regional impact assessment, and future scenario studies.

First, species richness is relatively insensitive to the described homogenisation process that eventually leads to species extinction. Species richness at the local (and even to the regional) levels (α diversity) can be expected to be stable or even to increase in response to the introduction of many new species due to human disturbances. New species will become more and more abundant, partly replacing original species, without necessarily leading to the extinction of the original species (McKinney & Lockwood, 1999). A process of increasing species richness has been observed between 1900 and 2000 in a period of large-scale industrialisation and demographic growth in the Netherlands. At the same time the abundance of the original species declined by a factor of three (ten Brink, 2000; ten Brink *et al.*, 2002). A sensitive indicator is crucial for policy decisions, so measures can be taken that can timely prevent (final) extinction.

Further, species richness is highly scale dependant, and regionally diverse. The number of observed species increases with the area of measurement. Larger homogeneous areas contain more space and resources to sustain more viable species populations. Larger areas also contain more types of communities. For instance, the total number of mammal species is higher in the USA than in Costa Rica, while the number of species per unit area is higher in Costa Rica (Reid *et al.*, 1993). Regional species diversity depends largely on the type of ecosystem and the taxonomic group of study (Gaston, 2000).

There are also several spatial and environmental gradients that influence species numbers. Going from polar and boreal regions, through the temperate zones to the tropics, the encountered number of species in large areas rises. This is often interpreted as the result of increased productivity (incoming radiation). However, higher productivity does not automatically result in more species at a more local level. In grassland systems, most species are found at intermediate productivity, and only a few highly competitive species will dominate high production grasslands. Within experimental gradients, a higher productivity can be attained by planting more species intermixed (increased crop diversity), thus effectively using more of the available resources (Purvis & Hector, 2000). When using the number of species in a comparative way, the different spatial and environmental gradients should be kept in mind.

Led by these arguments and the indicator criteria in mind (par 5.2.2.), the next section will put a focus on indicators based on species abundance. Patterns of abundance within species are clearly of fundamental concern for conservation.

Next to absolute levels, species numbers can be used in a relative way: expressed relative to the number of species occurring in pristine, unimpacted situations (RSROS: Mean relative species richness of original species). It is used for instance in showing the importance of continuous natural areas. Quantifying the species-area relationship is usually done with species number as indicator (c.f. Wilson and McArthur), but can also be performed with the area for minimum viable populations (Bouwma *et al.*, 2002; Smout *et al.*, in prep.) with the relative species richness (RSR) as indicator. As for the productivity relation, care must be taken when applying the area-biodiversity concepts at different spatial levels, i.e. local, regional to continental (van Vuuren *et al.*, 2006b).

5.2.5 Comparing different composite and aggregate indicators

As composite indicators are found more useful for policy makers, six composite indicators are described here. Several of the listed indicators are related to (natural) species abundance and abundance of threatened species, and will better describe the gradual changes in biodiversity loss, which is important for effective policy action. The indicators have been regularly implemented in official assessment reports, for instance the 2nd Global Biodiversity Outlook - GBO2 (CBD, 2006). Major features, pros and cons will be given (derived from (ten Brink, 2007):

1. Natural Capital Index (NCI)
2. Living Planet Index (LPI)
3. Biodiversity Intactness Index (BII)
4. Mean Species Abundance (MSA)
5. Species Assemblage Trend Index (STI)
6. Red List Index (RLI)

Other often used indicators are related to (sustainable) human use of available land and biomass (ecosystem use and footprinting).

7. Ecological Footprint (EF)
8. Human Appropriation of Net Primary Production (HANPP)

These indicators cannot be translated directly into a biodiversity value, but can serve as a proxy as they are related to the main drivers. They are also included in the recent Global Biodiversity Outlook 2 (CBD, 2006), and can have derived policy targets (such as for Protected Areas). They will be treated in the section on future projections.

Natural Capital Index - NCI

The NCI is based on the abundance of individuals of species, relative to the low-impacted or pre-industrial state. In essence NCI measures human impact. A distinction is made between the NCI-natural and NCI-agriculture. For NCI-agriculture, traditional agriculture is applied as baseline or reference situation. The mean species abundance is calculated as the product of the remaining ecosystem area (quantity) and the ecosystem quality (mean species abundance). The distinction between natural (self regenerating) and cultural ecosystems has been made for two reasons. First, traditional landscapes have their own specific biodiversity and cultural-historic features which are often highly valued (Hoogeveen *et al.*, 2004). Comparing these systems with natural ecosystems would make no sense. Second, ecosystem extent (quantity) is very easy to monitor and to model, even for poor countries, which makes it more feasible for global use. NCI has been used in UNEP's Global Environment Outlook 1 and 3 (UNEP/RIVM, 2004). The ecosystem quantity (extent) is based on land use and land cover monitoring, the ecosystem quality component is based on literature reviews, expert judgement and modelling exercises (UNEP, 1997).

Living Planet Index - LPI

The LPI is calculated from measured population sizes (i.e. species abundance) of a representative selection of species (for world ecosystems) relative to 1980. The LPI does not distinguish between natural and man-made ecosystems and is entirely calculated on the mean species abundance of a core set of species. For each species the first recorded measurement is used as baseline. This means that there is not a single baseline but a shifting baseline since 1970. In essence LPI measures human impact since 1970. The valuation principle is: the more individuals per species the better. LPI has been applied in various WWF reports (Loh & Wackernagel, 2004) and the 2nd Global Biodiversity Outlook (CBD, 2006).

Biodiversity Intactness Index - BII

The BII is based on the mean species abundance relative to the natural or low-impacted state at the ecosystem level. The valuation principle is naturalness, and no distinction is made between natural and agricultural ecosystems. The BBI is derived and calculated from land-use and land cover data. Each land use category has a fixed biodiversity value, based on field data and expert judgement. Effects of other pressures like climate change, fragmentation or N-deposition are not taken into account. In essence BII measures human impact by agriculture, extensive grazing and forestry. National parks are used as reference. It has been specifically designed for species-data poor regions, and has been applied in Southern Africa and in the South African assessment of the Millennium Ecosystem Assessment (Scholes & Biggs, 2005).

Mean Species Abundance - MSA

MSA is based on the mean abundance of individual species relative to the abundance in natural or low-impacted situations at the ecosystem level. No distinction is made between the natural and man-made ecosystems, contrary to NCI. It has been designed for global and regional assessments in which models calculate the future status for different scenarios. In essence MSA measures human impact. Therefore, the valuation principle is “naturalness”. It is not intended to highlight individual species under threat.

It can be easily linked to socioeconomic activities, and can distinguish the different pressures on biodiversity and sector contributions. By connecting the MSA calculation to integrated global change model frameworks, it can be used in future projections. It has been linked to the dynamic global environmental change model IMAGE (Bouwman *et al.*, 2006), and has been applied in the Biodiversity Outlook of the GBO2 Assessment (CBD & MNP, 2007), regional UNEP assessments (Fall of the Water, the Desert Outlook, (UNEP, 2006; UNEP GRID-Arendal, 2004), and will be used in the upcoming FAO/World Bank agricultural assessment, OECD’s Environment Strategy and Outlook and UNEP’s fourth Global Environment Outlook (UNEP, 2007).

Species Assemblage Trend Index - STI

STI gives the mean abundance of a species group compared to a reference year (i.e. 1980). These could be taxonomic groups, species of cultural interest, endemic species, migratory species, threatened species, etc. In essence STI measures human impact on a species group since the reference year. The valuation principle is: the more individuals per species the better. STI has been applied in various national and European reports. Examples are the European farmland bird and the butterfly indices. In The Netherlands, the UK and various other countries STIs have been made for birds, butterflies, large mammals, reptiles and other groups (de Heer *et al.*, 2005).

Red List Index - RLI

The RLI is based on weighting the extinction-risk of species from particular taxonomic groups. In essence RLI measures human impact -in terms of risk of extinction- per species group since a certain year (see also (Reid *et al.*, 1993). The valuation principle is: the lower the extinction-risk the better. Several varieties of RLI have been used all over the world. The RLI variety makes it difficult to understand its meaning. Trends indicate that risk are getting larger, but the meaning of a change from 100-85 in terms of how many birds are at risk and at what risk level remains unclear. Currently the RLI is redesigned to improve its communicative value.

Table 5.3 Comparison between six composite indicators on features and meaning

Indicator	**Level**	**Baseline or reference**	**Valuation principle**	**Species/area weighted**	**Meaning**
NCI	ecosystem	preindustrial	more natural the higher	Area	change in naturalness since industrialisation
BII	ecosystem	natural	more natural the higher	area and species	change in naturalness
MSA	ecosystem	natural	more natural the higher	Area	change in naturalness since industrialisation
LPI	ecosystem	1970 - □	more indiv. the higher	Species	change in species abundance since 1970
STI	species	1980	more indiv. the higher	Species	change in species abundance of group
RLI	species	extinction risk	less risk the higher	Species	change in extinction risk of group

Comparing indicators

The composite indicators form a relatively homogeneous group, but differ with respect to their principles (species numbers and/or abundance), the used reference situation (baseline), calculation methods (averaging and weighing) and other criteria (see Table 5.3).

Species abundance

NCI, BII, MSA and LPI are ecosystem-level indicators based on species abundance. However, they have different assessment principles:

- MSA, NCI and BII are measuring naturalness or human impact.
- NCI assesses agro-ecosystems separately with traditional agricultural ecosystems as baseline.
- LPI measures human impact since 1970.In absence of a specific baseline an increase in the abundance of any species (also introduced or invasive) is perceived as "good"

Species level

STI, RLI and LPI are species-level indicators based on species abundance within a species group.

They have different assessment principles:

- LPI and STI measure change compared to a reference year (the more individuals the "better").
- RLI is measuring the level of extinction risk. In the example above 1988 is set as baseline year. The various RLI varieties have different calculation procedures such as species selection, the use of a baseline year, including or excluding the rate of change in abundance, and others.

Modelling and monitoring

- BII, MSA and NCI are partly model-based and can be calculated by modelling land use. Therefore, all of them can be used for future projections, in conjunction with environmental and land-use change models. BII is calculated by modelling land use, using expert knowledge. BII has been used in projections at a regional scale, and is suitable in data-poor regions. In the models used for MSA and NCI a set of other human induced pressures are included as well.
- NCI has also been used in monitoring a sample set of species (at the national level, and is suitable for data-rich countries and regions).
- LPI and STI have been used in monitoring a sample set of species (suitable for data-rich biomes). They have not yet been used for projections, but this can in principle be done.
- RLI has been calculated by both monitoring and expert judgement of a sample set of species (suitable for data-rich regions). RLI is difficult to model, and to use in projections.

It does not make sense to declare one indicator better or worse. After all, suitability can only be determined in the context of the key questions of the target-audience. To describe a complex multi-faceted phenomenon as biodiversity, a single indicator will never show an overall picture. Several complementary indicators will be necessary. Lastly, the different implementations of reference or baseline situations make that the information supplied by each indicator is subjective to what is regarded as valuable. This value-ladenness must be kept in mind when policy actions are based on supplied information.

5.2.6 Valuable biodiversity and protected areas

Protected Areas

An often used indicator for monitoring the progress on biodiversity loss is the world-wide extent of protected areas. A derived CBD goal exists for this indicator, namely the protection of 10% of the surface of each of the main worldwide biomes. The status of protected areas can be distinguished in different categories that indicate the intensity by which an area may be used by humans. These vary from completely protected areas to areas that are managed for sustainable use. Protected areas are regularly monitored by the World Conservation Monitoring Centre (UNEP/WCMC). The database includes all presently protected areas worldwide that contain valuable elements for conservation.

Currently, protected areas cover about 12% of the Earth's land surface, which is about 17 million km^2. For the marine environment, a very limited area has been established. In 2003, the 10% target had been reached for 9 out of the 14 main terrestrial biomes. Especially temperate grasslands and lake systems do not reach the 10% target. There are also differences between geographical regions (CBD, 2006; IUCN & UNEP/WCMC, 2003).

Still, it is hard to judge from area information what the effect of reaching the Protected Areas target will be on the ultimate goal of the CBD Convention (to reduce that rate of further loss by 2010). Area figures alone are not very informative and need to be complemented by information on the level of protection and the effectiveness of management. In an analysis of the representativeness of the world's protected areas, it was concluded that 57% of all terrestrial biodiversity elements is represented by the current network alone, by (hypothetically) ignoring biodiversity outside protected areas. Fine scale spatial information on environmental attributes was used (an improvement of the mostly coarse scale global assessments using aggregated ecoregions), and relating this information to data on species occurrence. The used model takes 2 levels of biodiversity into account, local species richness and differences in species composition between locations (α and β diversity, respectively). The species richness is modelled as a function of its ecoregion and a vector of environmental variables. The dissimilarity aspect was modelled by determining (environmental) heterogeneity between cells within the same ecoregion.

Relevant for the subject of biofuel production is that protected areas contain valuable biodiversity, both in terms of representativeness and specific species with a high conservation value. Sustainable use is allowed in some IUCN categories, that clearly excludes intensive land-use (such as several bio-energy crops included under 1st generation). Especially temperate grasslands are underrepresented in the currently protected area network, and are at risk when they have a high suitability for growing crops. This is especially true for High Nature Value farmland areas that consist mostly of semi-natural grasslands (see par 5.2.7).

The network of protected areas continues to be expanded in order to increase the share of effectively protected biodiversity, but at the same time an important notion is that protected areas alone will never provide enough room for maintaining viable populations of all forms of biodiversity on earth. Conservation and protection of biodiversity outside protected areas remains complementary and necessary

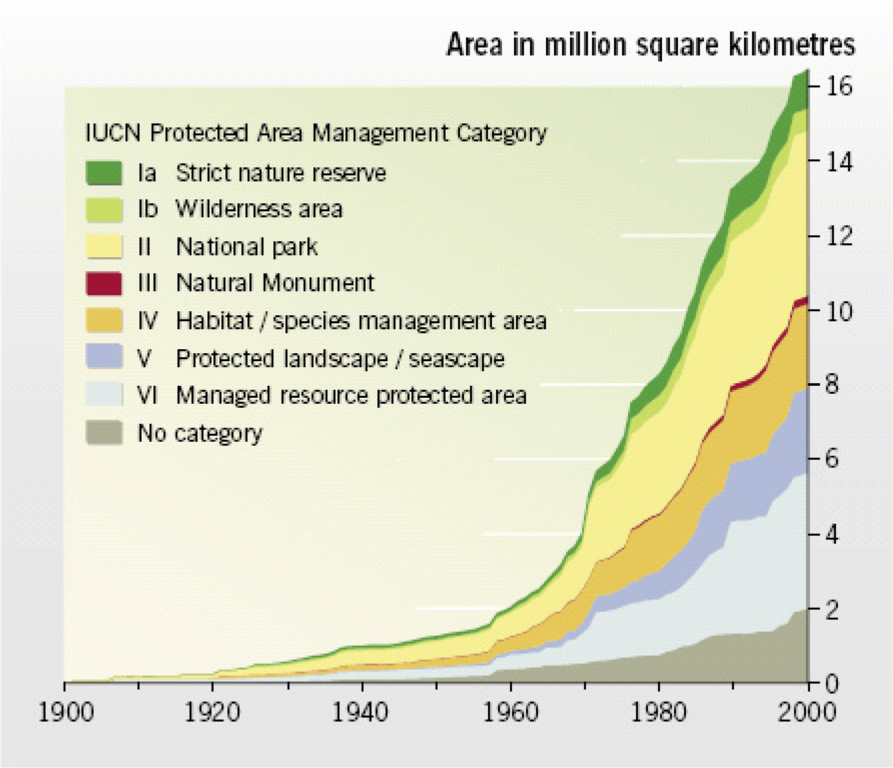


Figure 5.3 Trends in terrestrial surface under protection (CBD, 2006).

High Conservation Value areas

Next to legally protected areas, there are other valuable areas that should be excluded from growing bio-energy crops. In relation to this the concept of High Conservation Value (HCV) areas is useful. Their values show in biodiversity protection and for providing services and goods to local communities, for the poor in particular. Several types of HCVs are distinguished (see Box 5.1). Part of the HCV1, HCV2 and HCV3 categories are already included in the presently protected areas, but not all hot spot areas are effectively protected yet. An increased demand for biofuels may result in the loss of mainly tropical and subtropical hot spot areas. Examples of HCV4 areas are forest ecosystems with important functions related to hydrological cycles and carbon storage (both in soils and biomass), and vegetation protecting soils against erosion.

The HCV concept

The Forest Stewardship Council (FSC) initially developed the concept of High Conservation Value Forests, which refers to forest areas of outstanding value and critical importance. Since 1999, High Conservation Value Forests have been included in FSC forest management standards and certification. Forest managers are required to identify High Conservation Values (HCV) within forest management units and to manage these HCV areas in order to maintain or enhance the identified values, and to monitor the effectiveness of their management. The HCV concept has been applied primarily to forests, but it is also applicable to the management of other types of ecosystems. The HCV approach can be useful for land use and conservation planning.

HCVs include exceptional or critical ecological attributes, ecosystem services and social functions. There are six types of HCV areas, which have been derived from the initial definition of HCV Forests of the Forest Stewardship Council:

- HCV1. Areas containing globally, regionally or nationally significant concentrations of biodiversity values (e.g. endemism, endangered species, refugia).
- HCV2. Globally, regionally or nationally significant large landscape-level areas where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance.
- HCV3. Areas that are in or contain rare, threatened or endangered ecosystems.
- HCV4. Areas that provide basic ecosystem services in critical situations (e.g. watershed protection, erosion control).
- HCV5. Areas fundamental to meeting basic needs of local communities (e.g. subsistence, health).
- HCV6. Areas critical to local communities' traditional cultural identity.

Independent assessments within major forest management units on Sumatra identified HCV Forest areas covering 15-43 % of total timber concession areas.

Box 5.1. The High Conservation Value concept. Source: (HCV Resource Network, 2006).

Expanding the Protected Areas network

There is a need for prioritization for further conservation planning, and different criteria lead to different spatial patterns. Areas with a high threat and high irreplaceability (the close, threatened nature) are quite different from areas with a low threat and a high opportunity (the still wild, unimpacted nature). The Mediterranean and tropical environments are consistently emphasized as priorities over different prioritization schemes (Brooks *et al.*, 2006).

Expanding the network of protected areas has been worked out by UNEP-WCMC in several scenarios for use in the GEO4 assessment (UNEP, 2007). The expanded network contains both existing protected areas (nationally designated and international sites) and expands in priority ecoregions and hot spot areas for biodiversity (as indicated by WWF and Conservation International). In the most ambitious scenario (Sustainability First) the total area is expanded to contain 20% of all distinguished terrestrial biomes (65 in total), and the total protected area will reach more than 26 million km^2 by 2050.

5.2.7 Indicators for Agro-biodiversity

Biodiversity and agriculture

Most of the above discussed indicators are either on naturalness, ecosystem and protected area extent or species numbers. In general, human influences (also called drivers and pressures) reduce the biodiversity levels shown by these indicators. Next to these natural elements, specific human-influenced ecosystem types can be the subject for protection and conservation. About half of the European territory is managed by farmers. Agricultural practices have created new habitats for many species depending on open landscapes. As a consequence, many European species are dependent on diverse, traditional agricultural management systems that have a long standing history. The biodiversity aspects of agriculture discussed here are covered by the term **agro-biodiversity**.

Due to agricultural developments directed at increasing crop productivity of mainly monocultures (such as pesticide use, fertilization, increased tillage, drainage and irrigation), the traditional extensively managed systems are disappearing and so are the associated species and landscape elements. The farmland bird population trend is decreasing since 1980, and the difference with woodland birds is striking. Many populations of European birds that are characteristic for extensive agricultural systems are now included in the European Red List. (text cited from (Hoogeveen *et al.*, 2004)).

Opposite to intensification is the process of land abandonment, a common phenomenon in regions where agricultural productivity is low (i.e. extensive farming systems). Causes are land reform, structural change and declining viability of agriculture. Abandonment has affected many types of farmland including HNV farmlands. The HNV farmlands form a limited proportion of unmanaged land. The exact extent is not well known.

European Policy, indicators and measures
Within the European Union, there are specific goals and policy programs to protect and conserve this type of biodiversity. In 1998, ministers of the European Council adopted the "Resolution on Biological and Landscape Diversity". There are 3 main biodiversity fields mentioned in the European "Action Plan for Biodiversity in agriculture": genetic variety of domesticated organisms; wild flora and fauna related to farmland; and supporting systems (soil organisms, pollinators, predators).

Identification and definition of HNV farmlands is important for setting the stage. A HNV farmland indicator is being developed (IRENA framework). There are several subjects that describe elements of agro-biodiversity:

- Extent of different HNV farming systems with high biodiversity values
- Presence of small scale landscape elements
- Occurrence of species and populations of special interest
- Conservation status
- Soil biomass and indices of foodweb-complexity
- Crop and livestock diversity (traditional and local varieties; related to genetic diversity)

A preliminary analysis (Hoogeveen *et al.*, 2004) estimates that 15-25% of the European utilized agricultural area qualifies as HNV farmland, mostly in Eastern and Southern Europe. The following types are distinguished: farmland with a high proportion of semi-natural vegetation; farmland dominated by low intensity agriculture; mosaics of semi-natural and cultivated land; farmland supporting rare species or high proportions of (European or world) populations. They consist of habitats such as semi-natural grasslands, steppe areas and mountainous regions. Overall population trends of characteristic bird species are negative.

Several EU policies can be mentioned, specifically focused on HNV-farmlands.

- Support ecological and economical viability under the 2nd pillar of Common Agricultural Policies (CAP (support to less favoured areas)
- Site protection under EU directives (for habitats and birds)
- Establishing Natura 2000 sites and network for extensive agriculture
- Stimulation of organic agriculture is a supporting policy objective that may be beneficial for maintaining agro-biodiversity.

Among the suggested measures to conserve agro-biodiversity are maintaining the favoured land management practices, prevent land abandonment and prevent (renewed) intensification of extensively used and marginal farming systems. Further, next to conservation of the farming type itself, attention is needed to preserve landscape elements (hedgerows, thickets, ponds) and mosaic landscapes (comprising both managed as non-cultivated habitats).

HNVs and bio-energy production
In a study on the potential bioenergy production in Europe (EEA, 2006), several environmental criteria were used. Among others, extensively cultivated agricultural areas were excluded from transformation into arable land for bio-energy. A further description of this study can be found in the overview of scenario studies (par 5.4.3).

5.3 Biodiversity effects of growing energy crops

5.3.1 Introduction

The much cited review by (Berndes *et al.*, 2003) compared studies on the potential contribution of bio-energy to future energy supply. The strongly varying results are the consequence of uncertainties in land availability and yield estimates. It was also noted that the interaction between land uses, biodiversity and soil and nature conservation was insufficiently analyzed. For the present debate on the benefits of growing bio-energy crops on a large scale, it is vital that we gain more insight in the effects on biodiversity.

The purpose of this chapter is to provide a broad view on biodiversity effects reported in published literature (both peer reviewed papers as grey literature). In reviewing the literature, it is important to keep the different definitions and scales of observation presented in the previous section in mind. When presenting information and options to policy makers, the biodiversity definition must be made clear as measures can have opposite effects for different biodiversity types and at different scales. For instance, agricultural intensification can be a measure to keep agricultural areas from expanding and will reduce conversion of natural ecosystems, but at the same time it is a threat to present agro-biodiversity in extensively used systems. Local improvement of biodiversity by replacing intensive agriculture by bio diversity “friendly” bio-energy crops (perennial crops and short rotation forestry) may lead to shifts in production regions. The trade-offs will show in global assessments. Both types of studies will be reviewed here.

To effectively discuss literature findings, they have to be compared and confronted with a broad view on the biodiversity issue (with all its relevant aspects, indicators and scales). Therefore, the literature and existing reviews are screened on the following aspects:
- definition and indicators of biodiversity (broad – narrow)
    - absolute or species species number,
    - species abundance or population sizes,
    - landscape level indicators (patches, connectivity),
    - agro-biodiversity (restricted to species found in agricultural areas),
    - threatened species,
    - reference situations,
- specific land-use conversions addressed
- crop type and applied management (1st and 2nd generation)
- local, regional or global consequences
- long and short term consequences
- uncertainties involved

5.3.2 Biodiversity effects of land-use changes for growing bio-energy crops

5.3.2.1 Biodiversity effects of arable agriculture

First generation bio-energy is made from conventional agricultural crops such as
- temperate regions: maize, rapeseed, soybean, sugarbeet, wheat, in rotation systems;
- tropical: sugar-cane and oil-palm in more permanent production.

Large-scale production of 1^{st} generation bio-energy is likely to be an integral part of the existing food and feed production system, and will not further affect local (residual) biodiversity. Biodiversity is already under threat as a result of land conversion. Expanding agriculture has played an important role in that process (Christian *et al.*, 1994; Tilman *et al.*, 2001). Additional crop demands for bio-energy can lead higher total crop production and subsequent additional agricultural impacts on future land use. It can easily lead to continuation of current agricultural expansion and, as such, has the potential to affect biodiversity (positively or negatively) through altered habitat quality, pesticide use, nutrient inputs, tillage, soil erosion, water quality, landscape structure or other factors (Christian *et al.*, 1994) (Carey, 2005). The impact of these factors on biodiversity is a vast subject, not specific for the bio-energy debate. A recent review for the EEA in relation to the Bio-energy Directive (Carey, 2005), examined the effects on biodiversity of contemporary and alternative (such as low-input, integrated and organic farming) cropping systems, that can be relevant for bio-energy production. Important findings from this review are summarised here.

Local environmental impacts of arable agriculture (Carey, 2005)

During the past fifty years, the remarkable increases of food production have come at considerable environmental and human health cost. Very large areas of permanent grassland, dry steppe grasslands and wetlands have been replaced by arable agriculture with a huge loss of biodiversity. Studies of birds, butterflies, beneficial invertebrates and annual arable flowers have shown serious declines in some species associated with arable farmland in the late 20th century.

Declines in biodiversity across Europe, therefore, coincided with an increase in the intensity of agricultural production. The decline in farmland-birds and the intensification of agriculture are shown to be correlated. Several factors played a part in causing these declines. Farming became more specialized, fertilisers and crop-protection chemicals were improved and applied in increasing amounts. Non-cropped habitat was removed to enlarge field sizes. Crop rotations were simplified with an increase in winter cereal production. Farmers removed hedges and drained wetlands to increase agricultural production, with negative effects on especially breeding wader populations.

Birds, arthropods and earthworms are all detrimentally affected by pesticides; plant and earthworm abundance are affected by nitrogen input; and reduced tillage causes increases in weeds and invertebrates, and reduces earthworm mortality. Therefore, in most cases a reduction of chemical inputs and a reduction in severe soil disturbance will have ecological benefits.

Alternative cropping systems relevant for biofuel production, i.e. low-input and integrated management, have been studied on their biodiversity impacts. Compared to contemporary practices, integrated management can lead to higher soil species diversity, for several taxons or species groups. Especially, effects of reduced tillage were clear. But heterogeneity between farms can be larger than variation between contemporary versus alternative treatments. The structure and diversity of the surrounding landscape may be more important to field-inhabiting invertebrates than the farming system itself.

A major influence was found for landscape structure and not so much for the resources and crops themselves. A varied habitat-mosaic generally offers the greatest biodiversity and population viability benefit. This is especially important for birds, mammals and insects that move around in the countryside. Ecological benefits are shown from mitigation measures such as arable margins, beetle banks, conservation headlands and wild bird cover.

Further studies are needed to investigate differences between contemporary and alternative systems for a wider range of taxa. The effect of different productivities and related land-use is not discussed in this box, but relevant for an overall assessment.

From this review it is clear that reducing the intensity of land-use and the associated practices may be beneficial to species associated with arable farmland. This is supported by a review on biodiversity effects of organic agriculture by (Bengtsson *et al.*, 2005). Implicitly, both reviews focus on agro-biodiversity, and not so much on the pristine natural ecosystems and their biodiversity. This in turn means that the debate on biodiversity effects of growing 1st generation bio-energys is closely related to the debate on High Nature Values in agricultural areas.

A recent report on “Large-scale bio-energy production and agricultural land use – potential effects on farmland habitats and related biodiversity” by (Elbersen *et al.*, 2006) much supports this bio-energy assessment. They assessed the effect of any change in land-use on biodiversity and the environment as a whole in the EU. One of their main conclusions is that overall the pressure on farmland will increase because of the implementation of the bio-energy targets in the different member states. In more detail they concluded about the impact on biodiversity that especially the low input farmlands are at risk from a conversion to bio-energy crops.
The methodology used by (Elbersen *et al.*, 2006) is based on a storylines and a biodiversity assessment model. Starting point is the direct and indirect influences on biodiversity. Habitat fragmentation, diversification, canopy structure and soil cover are ‘direct’ influences and eutrophication, acidification, water balance effects and climate change are ‘indirect’ influences. They determined two main changes in landuse and farming practices most likely to influence biodiversity: 1) conversion of extensive land use categories to arable land (fallow, perm grass,

perm crops, abandoned land) and 2) changes within arable land (increase inputs, decrease inputs, dry to irrigate). They developed a set of impact tables showing for 16 land uses (from horticulture to scrubs in the Mediterranean) and a list of activities (e.g. use of fertilizers, herbicides, tillage etc., and a set of future – bio-energy-related – activities) the direction of the impact on biodiversity. The results are portrayed in terms of proportion of positive, neutral and negative impacts.

In conclusion, low intensity methods that generally show lower impacts can be advocated when the focus is on agro-biodiversity. It might be a motivation for current extensively used areas to be maintained, and not be converted to bio-energy production with contemporary production methods. For the GLOBIO model, the effects of different intensities of agricultural land-use (including the related practices) on the biodiversity indicator MSA are based on a separate review of literature studies. This has resulted in a range of values for remaining biodiversity (see Table 10.2 in (Bouwman *et al.*, 2006)).
The main remaining biodiversity issue for 1st generation bio-energy is whether they will be produced on existing agricultural lands or that additional land conversion will take place to accommodate for increased demand. This subject should be treated in combination with food production, land competition, global trade, yields and efficiency increases. For the biodiversity effects, the subject of land-use changes and competition among agricultural products (both high-input and alternative production methods) should be treated in integral, global analyses. Such an approach will show possible trade-offs or synergies between different products and different regions, in relation with the total short and long term biodiversity effects. There are only few of such studies, specifically geared towards bio-energy production (see section 5.4.3).

5.3.2.2 Biodiversity effects of growing second generation bio-energy crops

The bio-energy that is required to produce the 2nd generation of bio-energys is not only produced as integral part of the existing food and feed production system. The typical crops containing ligno-cellulose for bio-energy are perennial woody or grass species.

- trees, such as willow (*Salix* ssp.), oak (*Quercus* ssp.), pine (*Pinus*), poplar (*Populus*), eucalyptus (*Eucalyptus*);
- grasses, such as elephant grass (*Miscanthus giganteus*), reed canary grass (*Phalaris arundinacea*) and switchgrass (*Panicum virgatum*).

Comparative empirical studies on the biodiversity effects of large scale plantations for growing 2nd generation bio-energy are few and hard to find (Aratrakorn *et al.*, 2006; Carey, 2005). This lack of information is mentioned in many other articles (Anderson & Fergusson, 2006; Berndes *et al.*, 2003; Donald, 2004). We therefore suggest to include other, better studied and comparative (intensive or extensive) land use types that serve as proxies for bio-energy. For the following, information is used from (Christian *et al.*, 1994; Chung *et al.*, 2000; Hartley, 2002; Laurance & Laurance, 1996; Lindenmayer & Hobbs, 2004; Peh *et al.*, 2006) (Lindenmayer & Hobbs, 2004; Noss, 1983) (Londo, 2002).

The “original” biodiversity value (with a reference of pristine ecosystems) bio-energy crop depends on whether they are native or exotic to the production area. Native species are expected to harbour more biodiversity, because they may be associated with many species within the ecosystem. The exact relationships may not yet been known. Some crops provide more structural similarity to the natural vegetation, which can be a benefit for certain species for instance, if the original vegetation was forest, more species may be maintained if trees are planted instead of perennial grasses and if the original vegetation structure is mimicked, e.g. through multi-layered agro-forestry systems.

The 2nd generation types of bio-energy will be produced on permanent plots. For woody bio-energy crops, production systems will be used that closely resemble wood production systems, but possibly with an adapted, shortened rotation period (because of different quality standards). Suitable management systems from an economic point of view are the short rotation coppice systems (SRC), and fuelwood plantations using fast-growing tree species (such as Eucalyptus, Pine and Poplar). Next to woody species, high-productive perennial grasses are used, that are managed in more or less permanent management systems.

Next to the kind of crop being produced, the intensity of harvest may vary from harvesting only parts of the crop (oil palm can be harvested every 10 days! Cf. or cutting down entire trees (Pine, Eucalypt). Rotation type, stand age, amount of basal area removed and methods used to harvest the material are all relevant for biodiversity.
Management of mixed stands of different ages may help to approach the natural heterogeneity for the stand; as a consequence monocultures like plantations often have less biodiversity than mixed stands. The amount of original biodiversity is often directly linked to the amount of remnant vegetation left. Understorey vegetation, dead wood and native trees that provide food and nesting sites also contribute to conserving parts of the original habitat. The use of fertilizers and chemical pesticides can reduce the amount of biodiversity, although the effect of this is not well-studied.

Different measures as indicators for biodiversity can be given: Species richness relative to the original species richness (RSROS), and the relative abundance of the original species (MSA). The advantage of these two indicators is that they allow for comparison with other vegetation types, because they give a relative state compared to the original situation in pristine vegetation. Species inventories can never cover all organisms present, so most studies focus on only one species group or taxon (e.g. birds, plants, insects, mammals). According to Christian *et al.*, 1994 citing (Noss, 1983) particular attention needs to be paid to native species with specialized habitat needs and species that face habitat shortage on a regional basis, rather than simply managing for maximum numbers or species richness. Therefore, a comparison of numbers of unrelated species is not informative.

Based on the GLOBIO3 database of reviewed literature (that contains literature information to derive of MSA and/or MSROS values), we were able to define the relative species richness and relative species abundance for oil palm, perennial crops and a number of woody species such as willow and pine/oak. Palm oil values are well in the range of values found for plantations, and added to that category. Mean values and their variation (s.e. of mean) are well known, but a fair amunt of variation between individual studies exists (see Fig.5.4).

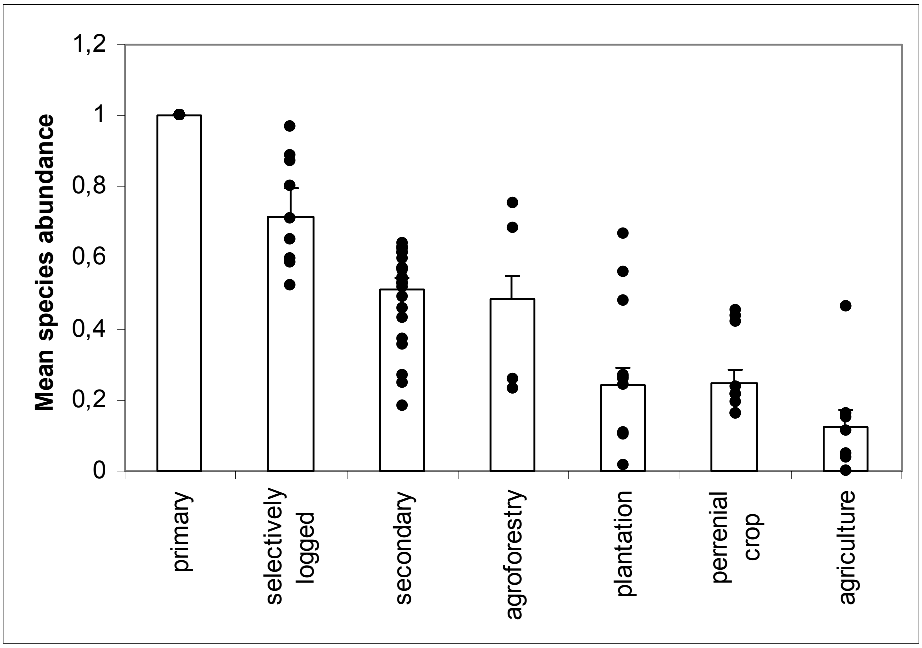


Figure 5.4 Mean species abundance of original species for different land-use types that form a range in land-use intensity (from unimpacted forest to completely converted forest). Data from GLOBIO literature database (july 2007).

5.3.2.3 Allocation of biofuel crops

The issue of land allocation is a main issue for possible biodiversity loss (expressed as naturalness), as original ecosystems get replaced by human influenced systems.

Conversion of natural areas
If natural vegetation is converted, bio-energy production will always have a negative effect on both local species richness and abundance (Christian *et al.*, 1994; Cook, 2000). Examples of the effect of conversion of natural forest into bio-energy (oil palm) plantations can be found in (Aratrakorn *et al.*, 2006; Chung *et al.*, 2000; Glor *et al.*, 2001). For Poplar plantations in North America, as an example of energy tree plantations that replace wildlands, the abundance and diversity of birds and/or mammals were lower in plantations than in forests and in non-wooded wildlands (Christian *et al.*, 1994). This effect is accentuated when access to the location was stimulated. Land conversions involve road construction, and opening up formerly closed areas facilitates additional human impacts and further land conversion.

Changing use of formerly agricultural areas
If the site had previously been managed in some other way, for instance as pasture or as waste land, the establishment of bio-energy crops may have relatively beneficial effects on local biodiversity. This is mostly the case for abandoned, degraded or deforested lands (Cook, 2000; Hartley, 2002).

Studies in Northern Europe and the United States demonstrate the success of planting woody bio-energy species (willow and poplar) in degraded areas to increase biodiversity (Berg, 2002; Christian *et al.*, 1994; Goransson, 1994; Kuzovkina & Quigley, 2005; Sage & Robertson, 1994).Growing a high diversity mixture of native grassland species on agriculturally degraded and abandoned prairies, was shown to lead to higher production than growing monocultures of Switchgrass (Tilman *et al.*, 2006). The mixture was defined as having a high biodiversity, focused on planted crops only. This is a very narrow biodiversity definition, even for agro-biodiversity.

Landscape structure effects
Bio-energy plantations can also benefit biodiversity when used as corridors, bufferzones and additional structural elements within in the agricultural landscape (Berg, 2002; Bowyer, 2001; Christian *et al.*, 1994; Cook, 2000; Devictor & Jiguet, 2007; Peh *et al.*, 2006).

Before answering the question about the impact of bio-energys on biodiversity a classification of agricultural and natural land use and its current biodiversity is necessary. Therefore six types of land uses are distinguished: crop/grassland (permanent and in rotation), set aside land, abandoned land, marginal land and land having an undisturbed natural vegetation and land with some disturbances (e.g. secondary forest).

First a clear definition of the distinguished land uses:
- Land having a undisturbed natural vegetation (e.g. primary forest): land where the existing plant and animal life is near pristine and in balance with climatic and soil conditions. The impact of man is absent or very limited to an extent that there is amply impact on the biodiversity.
- Land having a disturbed natural vegetation (e.g. secondary forests): land where the existing plant and animal life is affected by the impact of man, but sufficiently protected against degradation.
- Cropland/grassland: agricultural land used for planting crops or for meadows. The land is primarily used to produce food and feed for local, regional or for the worldmarket.
- Marginal land: In farming, poor-quality land that is likely to yield a poor return (It is the last land to be brought into production and the first land to be abandoned)
- Abandoned land: unused land, formerly used for agriculture or covered with its original vegetation. Abandonment is often the result of agro-ecological and/or economic constraints, or the local social-political situation.

- Set aside land: Is a proportion of the land that is temporally taken out of food production. The main reason for set aside is to reduce the risk of food surplusses. Under certain

Table 5.4 The short-term biodiversity impact of land converted from actual land uses to annual and perennial bio-energy crops in both temperate and tropical regions. Values refer to mean species abundance (MSA) and "from 1.0 to 0.1" means a drop from the highest level of biodiversity (1.0) to the lowest level (0.1) and the loss is 0.9.

Land use	Climate regime and cropsystem	Annual crops		Perennial crops		
		Oilcrops (rapeseed, soybean)	**Cereals** (wheat, maize, straw)	**Oilpalm**	**Grass** (miscanthus, switchgrass)	**Woody** (willow, poplar, pinus, eucalyptus)
	Bio-energy Generation	1st	1st / 2nd	1st	1st / 2nd	2nd
Undisturbed Natural vegetation (near pristine)	temperate	from 1,0 to 0.1 result: — **0.9**	from 1,0 to 0.1 result: — **0.9**	n.a.	from 1,0 to 0.3 result: — **0.7**	from 1,0 to 0.3 result: — **0.7**
	tropical	from 1,0 to 0.1 result: — **0.9**	from 1,0 to 0.1 result: — **0.9**	from 1,0 to 0.3 result: — **0.7**	from 1,0 to 0.3 result: — **0.7**	from 1,0 to 0.3 result: — **0.7**
Disturbed Natural vegetation (secondary forest)	temperate	from 0.5 to 0.1 result: — **0.4**	from 0.5 to 0.1 result: — **0.4**	n.a.	from 0.5 to 0.3 result: — **0.2**	from 0.5 to 0.3 result: — **0.2**
	tropical	from 0.5 to 0.1 result: — **0.4**	from 0.5 to 0.1 result: — **0.4**	from 0.5 to 0.3 result: — **0.2**	from 0.5 to 0.3 result: — **0.2**	from 0.5 to 0.3 result: — **0.2**
Existing cropland/ grasslands	Temperate: in rotation intensive	from 0.1 to 0.1 result: **0.0**	from 0.1 to 0.1 result: **0.0**	n.a.	from 0.1 to 0.3 result: + **0.2**	from 0.1 to 0.3 result: + **0.2**
	Temperate: Permanent intensive	from 0.2 to 0.1 result: — **0.1**	from 0.2 to 0.1 result: — **0.1**	n.a.	from 0.2 to 0.3 result: + **0.1**	from 0.2 to 0.3 result: + **0.1**
	Tropical: agro-forestry	from 0.5 to 0.1 result: — 0.4	from 0.5 to 0.1 result: — **0.1**	from 0.5 to 032 result: — **0.2**	from 0.5 to 0.3 result: — **0.3**	from 0.5 to 0.3 result: — **0.2**
	Tropical: in rotation extensive	from 0.3 to 0.1 result: — **0.2**	from 0.3 to 0.1 result: — **0.2**	from 0.3 to 0.2 result: — **0.1**	from 0.3 to 0.2 result: — **0.1**	from 0.3 to 0.3 result: **0.0**
Set aside land (policy in some. developed regions)	temperate	from 0.3 to 0.1 result: — **0.2**	from 0.3 to 0.1 result: — **0.2**	n.a.	from 0.3 to 0.3 result: — **0.0**	from 0.3 to 0.3 result: **0.0**
	tropical	n.a.	n.a.	n.a.	n.a.	n.a.
Marginal land	temperate	from ± 0.3 to 0.1 result: — **0.2**	from ± 0.3 to 0.1 result: — **0.2**	n.a.	from ± 0.3 to 0.3 result: — **0.0**	from 0.3 to 0.3 result: **0.0**
	tropical	from ± 0.3 to 0.1 result: — **0.2**	from ± 0.3 to 0.1 result: — **0.2**	from ± 0.3 to 0.2 result: — **0.1**	from ± 0.3 to 0.3 result: — **0.0**	from ± 0.3 to 0.3 result: **0.0**
Abandoned land	temperate	from ± 0.3 to 0.1 result: — **0.2**	± 0.3 to 0.1 result: — **0.2**	n.a.	from ± 0.3 to 0.3 result: — **0.0**	from ± 0.3 to 0.3 result: **0.0**
	tropical	from ± 0.3 to 0.1 result: — **0.2**	from ± 0.3 to 0.1 result: — **0.2**	from ± 0.3 to 0.2 result: — **0.1**	from ± 0.3 to 0.3 result: — **0.0**	from ± 0.3 to 0.3 result: **0.0**

The different possible land-use changes are structured in Table 5.4, and shows where local losses or gains can occur. This matrix analysis can be used in assessing local impact studies.
Land used for large scale agriculture and commercial forestry have a much lower biodiversity compared to natural land use. It is assumed that land used to cultivate crops and timber for the production of biofuels are managed in the same way as agricultural crops for food or fodder and commercial timber production. Subsequently the MSA value is assumed to be similar to the value of the agricultural land and commercial forests (see MSA matrix). The MSA approach only

reflects the land use as such and not the main ecological structure of the whole area nor does it reflect specific management options. It is assumed that adapted management and attention to the main ecological structures of the area has an overall positive impact on the biodiversity and if implemented well this could lead to higher biodiversity values. Some examples of adapted management are: no or limited tillage, multiple and intercropping, focus on improvement of soil carbon content, and mixture of tree species. Example of main ecological structures: connected zones and spots with a natural land cover, variation in land use (e.g. mixture of forest and cropland). The assumption is that the highest achievable MSA value for all biofuel crops and woody species is 0.3. The (negative) impact on the yield is estimated at 10-20% (partly because of area that is allocated for nature and partly because of the adjusted management). The preliminary results show that full attention for ecology leads to higher MSA value, but this has a negative impact on the net yield.

5.3.2.4 Impact of bio-energy production on soils and soil carbon

Soils hold about three times more carbon than terrestrial vegetation and twice as much as the atmosphere. Land use change, inappropriate agricultural practices and climate change can all lead to a net release of carbon from soils to the atmosphere, enhancing the problems of greenhouse gas release (Milne *et al.*, 2007). The highest levels of carbon are stored in organic soils (>20% organic matter in the top 40 cm of the soil). Mineral soils have much lower levels of organic matter (1-5% organic matter in the topsoil). The loss of soil organic matter is important not only because it equals 7.5% of the total carbon released to the atmosphere by combustion of fossil fuels, but because soil organic matter is critical for soil productivity. The soil's moisture holding capacity, density, aeration, and ability to supply and conserve plant nutrients all are improved by soil organic matter (Anderson & Coleman, 1985; Downing *et al.*, 1995).

The loss of organic matter in soils is strongly related to the management of the soil. In management systems with a high frequency of tillage (what is the case with most annual cropping systems) the loss of organic matter does increase, whereas in management systems with a more permanent cover (perennial grasses) the losses are far less or not occurring. In case erosion by wind or water does occur, the organic matter content can drop fast, which makes the soil even more susceptible for erosion. Especially the mineralization of organic soils, caused by lowering the water levels and inappropriate agricultural use of the soil, can lead to very strong decreases in soil organic matters and leads to high carbon emissions.

Soils cultivated with perennial grasses (e.g. switchgrass) or woody energy crops seems to be much less susceptible for losses of soil organic matter compared to annual crops with a high tillage frequency, especially during heavy rains (Downing *et al.*, 1995). For the assessment of the impact of bio-energy crops on the soil it is necessary to differentiate between the type of crops that are cultivated and the susceptibility of the soil for loss of organic matter. Conservation practices can support to prevent soil organic matter losses and prevent decline in productivity and soil degradation.

Neglecting the fertility and carbon content of the soil may cause significant drop in yields and subsequent lower carbon efficiency and makes soils susceptible for physical and chemical degradation.

5.3.3 Conclusions from studies on local biodiversity impacts

- Local impact studies vary substantially in their characteristics (crops, land allocation and indicators used). There are only few studies that clearly define the biodiversity indicator, and quantify the biodiversity effects. Those that give quantified information mostly apply to forest ecosystems, and varying effects were noted (from gains to slight loss).
- Papers reporting conversion of pristine vegetation to productive land-use always note a loss in original biodiversity at the local scale.
- Papers that report positive influences of growing bio-energy crops are usually related to using abandoned agricultural fields and turning them in to mixed grass or tree plantations, using native species. Quantitative comparisons with pristine vegetation types are usually not

made. The reported biodiversity indicators for perennial grasses, and mixed cropping systems implicitly refer to agro-biodiversity. Usually a limited amount of taxa is included.

- Placement of energy crops, rather than traditional agricultural crops, on cropland (rowcrops, small-grain fields) may reduce use of pesticides, reduce soil erosion and improve water quality. All of these changes represent clear ecological benefits (that will show up in biodiversity indicators). If bio-energy plantations instead were to replace forests or other wildlands there may be negative effects in some aspects. Although some energy tree crops have been established in wildlands, almost all have been placed in former croplands, so the comparisons most relevant to biodiversity concerns presently and in the near future are between plantations and croplands.
- First generation crops (oilcrops, cereals, sugarcane) are likely to have a stronger negative impact on biodiversity than second generation crops (willows, poplar and grasses). As a result, biodiversity might also increase if first generation bio-energy crops are replaced (on the same land) by second generation crops.
- In terms of the land-use matrix: the matrix of possible land-use changes (and associated short-term local biodiversity changes) gives a framework in which most literature on local impacts can be placed.

5.3.4 Effects of climate change on biodiversity

An important positive effect of biofuels is a reduction of greenhouse gas emissions compared to fossil fuels, although biofuels are not CO_2-neutral. Relevant for the biodiversity assessment is therefore the contribution of biofuels to reducing the effect of climate change on biodiversity.

The impact of climate change on the environment and biodiversity has been a fast growing area of research. Much information on this issue has been reviewed by the IPCC Working Groups, recently for the 4th IPCC Assessment Report (report “Impacts, Adaptation and Vulnerability”; (IPCC, 2007)). A summary is presented in the text box below. The report makes a distinction between already observed changes in ecosystems and species distributions, and the outcome of modelling exercises that try to predict future changes in biodiversity as a response to climate change.

The WGII reports significant observed changes in biological systems during the last three decennia as a response to changes in the global climate. Most of the reviewed studies were performed in temperate regions on the Northern hemisphere. But effects have been noted for all continents, including Antarctica. Further, changes have been noted for terrestrial, aquatic and marine systems (especially coral reefs). Shifts in species distributions have been recorded, where species from warmer zones invade more Northern areas, and mountainous areas. The length of the growing season for plants has been expanded, and bird migration is taking place earlier in the season. As a result, there is increasing asynchronity between predator-prey and insect-plant systems, with mostly negative effects (Parmesan & Yohe, 2003). Higher temperatures and drier conditions increase the risk of fire in the Mediterranean and North America.

Possible future effects of climate change are becoming clearer. The WGII report states that about 20-30% of all plant and animal species are at risk of extinction when the global temperature will rise 2 or 3 K above pre-industrial levels. About 15% of the terrestrial surface will undergo major changes. Especially tundra, boreal forests, mountain areas, the Mediterranean area, mangroves, salt marshes, coral reefs and polar areas are at risk. A related subject is the increased release of carbon from peat systems, permafrost areas and forests. This feed-back mechanism will add to the climate change problem.

A problem for assessing the beneficial effects of biofuels is the inherent uncertainty and unpredictability of future changes in biodiversity, and the different quantitative information that different models and indicators supply. Many of the published future projections use models that embrace the concept of “environmental envelopes”, the set of environmental conditions that can be related to present day species distributions. This type of models can explain much of the global distribution of species diversity, especially plants (Bakkenes *et al.*, 2002; Ferrier *et al.*, 2004; Kleidon & Mooney, 2000; Kreft & Jetz, 2007). Climate modelling can predict changes in different climatic variables. This information is used to calculate future areas with the same conditions. The change in suitable areas and the areas with a more or less stable climate form the basis for the calculated biodiversity response. In this much used approach, the assumption is that species preferences are constant, and species will respond as part of an entire community that moves simply north or south. This leaves competition and adaptation to new situations (genetic shift) out of consideration. A recent article discusses the probability that the distribution of future environmental conditions will result in new climatic combinations (Fox, 2007). New combinations will arise in 4% to 39% of the world land area, and these areas will develop new no-analog ecosystems. Simultaneously, existing climatic conditions will disappear in 4% to 48% of the world. The article suggests that maintaining present day native ecosystems may turn out to be impossible. This discussion adds to the considerable sources of uncertainty in the biodiversity response, and the partly unpredictable nature of biodiversity change.

From the executive Summary of IPCC Working group 2, chapter 4
(IPCC, 2007)

During the course of this century the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate and in other global change drivers (especially land use change and overexploitation), if greenhouse gas emissions and other changes continue at or above current rates (high confidence). By 2100 ecosystems will be exposed to atmospheric CO2 levels substantially higher than in the past 650 000 years, and global temperatures at least among the highest as those experienced in the past 740 000 years (very high confidence). This will alter the structure, reduce biodiversity and perturb functioning of most ecosystems, and compromise the services they currently provide (high confidence). Present and future land use change and associated landscape fragmentation are very likely to impede species' migration and thus impair natural adaptation via geographic range shifts (very high confidence).

Several major carbon stocks in terrestrial ecosystems are vulnerable to current climate change and/or land-use impacts and at a high degree of risk from projected unmitigated climate and land-use changes (high confidence). Several terrestrial ecosystems individually sequester as much carbon as is currently in the atmosphere (very high confidence). The terrestrial biosphere is likely to become a net source of carbon during the course of this century (medium confidence), possibly earlier than projected by IPCC's Third Assessment Report (low confidence). Methane emissions from tundra frozen loess ("yedoma", comprising ~500 Pg C) and permafrost (comprising ~400 Pg C) have accelerated in the past two decades, and are likely to accelerate further (high confidence). At current anthropogenic emission rates the ongoing positive trends in the terrestrial carbon sink will peak before mid-century, then begin diminishing, even without accounting for tropical deforestation trends and biosphere feedback, tending strongly towards a net carbon source before 2100 (high confidence), while the buffering capacity of the oceans will begin to saturate. While some impacts may include primary productivity gains with low levels of climate change (<~2ºC mean global change above pre-industrial levels), synergistic interactions are likely to be detrimental, e.g. increased risk of irreversible extinctions (very high confidence).

Approximately one fifth to one third of species assessed so far (in an unbiased sample) are likely to be at increased risk of extinction if global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels (medium confidence). Projected impacts on biodiversity are significant and of key relevance, since global losses in biodiversity are irreversible (very high confidence). Endemic species richness is highest where regional palaeoclimatic changes have been muted, providing circumstantial evidence of their vulnerability to projected climate change (medium confidence). With global average temperature changes of 2°C above pre-industrial levels many terrestrial, freshwater, and marine species (particularly endemics across the globe) are at a far greater risk of extinction than in the geological past (medium confidence). Globally ~20% to ~30% of species (global uncertainty range from 10% to 40%, but varying among regional biota from as low as 1% to as high as 80%) will be at increasingly high risk of extinction by 2100. Current conservation practices are generally poorly prepared to adapt to this level of change, and effective adaptation responses are likely to be costly to implement (high confidence).

From the executive Summary of IPCC Working group 2, chapter 4
Continued

Substantial changes in structure and functioning of terrestrial ecosystems are very likely to occur with a global warming of > 2 to 3°C above pre-industrial levels (high confidence). Between ~26% (WGI B1 scenario; 1.7ºC warming) and ~37% (WGI A2 scenario, 3.7ºC warming) of extant ecosystems will reveal appreciable changes by 2100, with some positive impacts especially in Africa and the southern Hemisphere arid regions, but extensive forest and woodland decline in mid to high latitudes and in the tropics, associated especially with changing disturbance regimes (especially through wildfire and insects).

Substantial changes in structure and functioning of marine and other aquatic ecosystems are very likely to occur with a mean global warming of > 2 to 3°C above pre-industrial levels and the associated increased atmospheric CO2 levels (high confidence). Climate change (very high confidence) and ocean acidification (medium confidence) will impair a wide range of planktonic and shallow benthic marine organisms that use aragonite to make their shells or skeletons, such as corals and marine snails (Pteropods), with significant impacts particularly in the Southern Ocean, where cold water corals are likely to show large reductions in geographic range this century. Substantial loss of sea ice will reduce habitat for dependant species (e.g. Polar bears) (very high confidence). Terrestrial tropical and sub-tropical aquatic systems are at significant risk under at least WGI A2 scenarios; negative impacts across ~25% of Africa by 2100 (especially southern and western Africa) will cause a decline in both water quality and ecosystem goods and services (high confidence).

Ecosystems and species are very likely to show a wide range of vulnerabilities to climate change, depending on imminence of exposure to ecosystem-specific, critical thresholds (very high confidence). Most vulnerable ecosystems include coral reefs, the sea ice biome and other high latitude ecosystems (e.g. boreal forests), mountain ecosystems and mediterranean-climate ecosystems (high confidence). Least vulnerable ecosystems include savannas and species–poor deserts, but this assessment is especially subject to uncertainty relating to the CO2 fertilization effect and disturbance regimes such as fire (low confidence).

5.4 Survey of impact assessment studies

5.4.1 Examples of life cycle analysis

Many LCA-studies on biofuels focus on greenhouse gas emissions. A smaller number of studies take land-use into account, mainly related to the cultivation of energy crops. In both cases an important issue is the allocation of process emissions and land used to biofuels in case the same processes deliver other products as well (animal feed, straw, glycerine etc.). It is mostly based on the economic values of the different products, implicating the effect will change only because of price fluctuations. A more physical approach could be an alternative. An interesting attempt is System Perturbation Analysis (de Ruyck *et al.*, 2006).
Only a few studies present combined results as reductions of greenhouse gas emissions per hectare. For some specific biomaterials values of more about 20-40 tonnes CO_2-eq/ha (Dornburg *et al.*, 2004) are possible, but in most cases these values are lower. For liquid biofuels, based on present technology, emission reductions ranging from almost zero to about 12 tonnes CO_2-eq/ha are reported (Ros & Montfoort, 2006) with relatively higher values for biofuels based on sugarcane, palm oil and wood.

What do these results mean for the overall effect on biodiversity? Because of the many uncertainties, already discussed in 5.3.4 it is hard to give a representative answer. In one study (Ros & Montfoort, 2006) the following assumptions have been made:

- The land used for the cultivation of crops would otherwise be or (on the long term) become nature
- The biodiversity value of the land used has been neglected
- MSA is used as an indicator
- Only the impact of land-use and the change of global temperature on the quality of the original biodiversity has been calculated
- Changes in carbon content of the soil because of land-use changes are not taken into account

- The change of temperature is assessed for the year 2100 to include long-term effects, based on IPCC-scenarios.

A neutral effect, i.e. the same positive effect of reduced greenhouse gas emissions as the negative effect of a change in land use, was calculated for an emission reduction 20 ± 10 CO_2-eq / hectare in a well-to-wheel analysis for a biofuel.

It has been discussed that biodiversity values for energy crop cultivation cannot be neglected completely. So, the biodiversity values as reported in 5.3.2.4 have been applied to assess their effect. For 1st generation crops in Europe this correction is no more than 10%, showing the net impact of those biofuels on global biodiversity is negative, because the actual reductions are lower than the calculated value for a neutral effect. In case of higher biodiversity values in cultivation practices the lowest value of the range could be a factor 1,5 lower (neutral effect for reductions of 18 ± 12 CO_2-eq / hectare), making the actual impact on the MSA-value of some of some of the 2nd generation biofuels rather uncertain.

5.4.2 Overview of scenario studies

The subject of land-use changes and competition between agricultural products (both high-input and alternative production methods) should be treated in integral, global analyses. These can capture both the short-term effects of land-use changes, and the long term effects of (avoided) climate change. Such analyses can show possible trade-offs or synergies between different products and different regions, and trade-offs between integral short and long term biodiversity effects. However, there are only few studies specifically geared towards bio-energy production.

Several scenario studies are briefly described and compared. Ideally, assessments should consider:

- short term land-use dynamics, with and without bio-energy production
- future effects of climate change on biodiversity (no mitigation scenarios)
- effects of taking climate change mitigation policies
- effects of biofuel production, as part of the portfolio of measures
- (autonomous) developments in agricultural areas

There are hardly any studies (up to 2006) that treat all elements. Therefore we include several scenario studies that do not explicitly treat bioenergy production and effects, but treat either agricultural expansion, changes in human land-use or climate change effects, and that use different indicators of biodiversity. These elements are all elements of the present biodiversity debate.

An important issue in reviewing scenario studies is the reference situation: one may assess changes compared to the current situation – but also compared to the potential situation in the future without bio-energy use. If future agricultural productivity will increase and stabilising population numbers will lead to a decrease in area for food production, this land may either be used for bio-energy production or be converted into natural land. The evaluation of this trade-off depends on the reference point.

Scenario studies without bioenergy

Biodiversity Scenarios for 2100 (Sala, 2000)

This study presents an analysis on the impacts of global environmental change on future biodiversity. Biodiversity is broadly seen and encompasses all scales. Several impacts are presented on a qualitative scale and are partly based on expert opinion. Agricultural fields are left outside the analysis, so implicitly the definition refers to “natural biodiversity”. Marine environments were also not considered.

By individually ranking impacts (land-use change, climate change, N-deposition, elevated CO2, and biotic exchange) and biome sensitivities to these impacts (qualitative approach, including expert judgement), it was possible to identify a ranking order of the different threats. The authors applied a business-as-usual scenario without climate change mitigation policies. Both for global biodiversity as in the Mediterranean and grassland biomes, land-use change is the most important factor that will cause further biodiversity degradation. Climate change was identified as the next important impact factor for the future.

Agriculturally driven global environmental change (Tilman et al., 2001)
The authors state that "conversion of natural ecosystems … (among other agricultural impacts) …. to agriculture may rival climate change in environmental and societal impacts". Further agricultural development and shifts in production regions are important factors for further conversion of natural ecosystems, mainly tropical savannah and forests. Biodiversity will suffer from this, as the total natural area decreases (habitat destruction). At the same time, land is abandoned in temperate developed regions, like Europe, which creates possibilities for biodiversity restoration or other uses (biomass crops).
Growth of global GDP is projected to increase by a factor 2.4 by 2050, while the world population grows from 6 to 9 billion people. By using linear fits between agricultural variables (N- and P-use, irrigated land, crop land and pastures, pesticide use) and indirect drivers as GDP and population, they projected substantial increases (factors between 1.9 to 3.9) in environmental impacts by 2050. For cropland and pastureland, increases were projected of 23% and 16% by 2050, leading to total land use of, respectively 19 and 40 million km^2, together occupying 45% of the global terrestrial surface (132 million km^2). Because at the same time a net withdrawal from agricultural land use is expected for developed countries, the net loss of natural land occurs mainly in developing countries. Expansion is projected to occur mainly in Latin America and Sub-Sahara Africa, and will lead to the loss of about a third of the remaining tropical and temperate forests, savannas and grasslands.
The assumptions (and therefore uncertainties) are that past management practices and improvements will continue in a trend like fashion, and that diets will be richer in meat. The projections for global agricultural developments are in line with the EUruralis-1 and GBO2-outlook results. Dynamic modelling is necessary to include changes in policies, drivers and technology. The authors advocate an environmentally sustainable agricultural revolution, including many examples of good practice options and solutions.

Extinction risk from climate change (Thomas et al., 2004)
Using the relations between present day species distribution and climate variables, individual species "climate envelopes" where derived. These were used to assess the stable area for species distribution under different climate change scenarios up to 2050. Next, using the species-area relationship, the consequences of suitable area reductions are calculated. Resulting effects of climate change are expressed as the percentage of species with an "increased risk of future extinction" (the authors explicitly state that this is not the same as the number of species that will go extinct). This approach assumes that current envelopes are retained and can be projected.

Three scenarios were examined that differ in climate-warming (from below 1K to above 2K by 2100). For the mid-range scenario, the authors predict that 15-37% of sampled species from different taxa will be "committed to extinction". A further differentiation was made for species with high abilities for dispersal, and species with a low ability (endemics).

Agricultural developments and biodiversity effects in the EU (Reidsma et al., 2006; Verboom et al., 2007)
The EUruralis 1 project contains scenarios about future developments in the rural environment of EU member states (old and new). The scenarios do not include targets for bioenergy production, but the study does show important effects of agricultural developments and especially land abandonment, that are crucial for the bioenergy debate. Especially production of 1st generation crops will have similar effects as the agricultural developments.

Scenarios were derived from the IPCC-SRES scenarios and were focused on future developments in cropping systems, grazing systems and organic farming. Biodiversity consequences of area changes (agricultural area expansion, land abandonment, urban area expansion) and changing management practices (increased intensification, organic farming and more environmental friendly practices) were analysed. The analysis uses the "naturalness" approach (MSA) and relative species richness (RSR). Further, positive biodiversity effects were included for organic farming. Organic farming effects are based on both species richness and abundance, relative to conventional farming (as is the usual and logical approach in literature; see for instance (Bengtsson et al., 2005; Maeder et al., 2002). Explicit attention is given to soil organisms.

Total agricultural land is decreasing in most scenarios. When at the same time crop productivity strongly increases, the average biodiversity in agricultural areas goes down. The biodiversity gain in areas taken out of production, which are assumed to restore to natural areas, is not enough to compensate for this loss. The abandoned areas are assumed to be extensive (marginal) production systems, with a relatively high (agro-)biodiversity value. Alternatively, when productivity increase is low and more environmental friendly management practices are applied, less area is taken out of production that can be used for nature restoration. In this case, the biodiversity balance is slightly positive. Additional scenarios with increasing areas of cropland for production of 1st generation bioenergy crops will very probably cause more biodiversity losses.

The EUruralis scenario exercises show the importance for the biodiversity balance (or sensitivity) of intensification, land abandonment and nature restoration. They leave the issue of agricultural biodiversity and High Nature Value farmlands (HNVs) as discussion point, as these are not covered by the indicator (Hoogeveen et al., 2004).

Scenario studies with bio energy production

The ecological overshoot of the human economy (Wackernagel & Rees, 1996)
In this much cited study, the required area of productive land for human consumption is calculated. This is called the “Ecological Footprint” (EF). It includes the areas for food, wood and energy production. The main point of this study is that the Earth is not able to sustainably supply all the required goods. Already in the 1980’s, the total required area is larger than the total area of bio-productive land. This so-called “overshoot” reached a value of 20% in 2001 (WWF 2004). The overshoot can implicitly be seen as the ultimate consequence of meeting the total world energy needs by compensating GHG-emissions by growing forests, added to the required land for producing food crops and wood. The footprint from bioenergy is about 50% of the total EF in 1999 (WWF, 2002).

Much criticism has been put forward on the EF approach, both on the methodology and some value-laden choices. See for instance the forum of the Journal of Ecological Economics (van den Bergh & Verbruggen, 1999), (VROM-raad, 1999). An important assumption of the EF approach is that all energy-needs are translated in land that is needed to absorb the CO2-emissions from fossil fuel combustion. Thus, all energy use is taken into account as “virtual“ or hypothetical land use. Alternative sources of energy generation without CO2-emissions are neglected. Ironically, present initiatives to supply substantial amounts of energy by biomass production replaces the “virtual” land-use by real land-use.

Footprint scenario studies using the IPCC-SRES scenarios have been performed by (van Vuuren & Bouwman, 2005). They left the virtual land use for energy use out of consideration. The actual land-use for food and wood increased from 5.4 Gha in 2000 to 6–8.2 Gha in 2050, depending on the different scenario, which translates in a 10–50% increase. Future crop yield improvements will partly offset this increase. Applying a scenario study for biomass energy will probably show more or less similar increases for energy. A study by WWF (2002) calculated the EF of two SRES scenarios, and showed an “overshoot” of 80-120% for 2050. However, it is not very realistic to assume that all future energy needs will be met by growing biomass.

Another major point of criticism is that the method is unable to include the environmental impacts from different forms of land management (pesticide and water use, P- and N-emissions). Including the impact of land-management next to the land-use itself, has in fact been implemented with the MSA indicator (Rood *et al.*, 2004). The MSA indicator combines both area changes due to human use and land quality changes due to environmental impacts

(MSA = Δ areas-quantity x Δ areas-quality). The basic dimension of MSA is natural land area (km^2 natural land), and therefore very much related to the EF concept. The consequences of including the area needed for biofuel production have been integrally shown in the GBO2-Outlook study (CBD & MNP, 2007).

An approach that is closely related to EF is the calculation of the Human Appropriation of Net Primary Production (HANPP). In this indicator, the percentage of the world net photosynthetic capacity is calculated that is used for human consumption (for instance, (Imhoff *et al.*, 2004)). Just like EF-studies, these type of studies show the local unbalance between consumption and production. Global trade can fulfil the unbalanced local needs, and this leads to using area “elsewhere”.

Bioenergy production in Europe without harming the environment (EEA, 2006)
This scenario specifically addressed the potential to produce bio-energy within the EU-25 from different resources (agricultural crops and residues, waste, forest residues and fellings), under the constraint of several environmental criteria. This approach seeks to minimize the environmental and biodiversity impacts of the debated bioenergy production The analysis concludes that within Europe there is a potential to supply 15-16% of EU-25 primary energy needs by 2030, with a total capacity of 12,6 EJ. This will avoid 400-600 Mton CO2.

The applied criteria include: 20-30% of land-use for environmentally friendly agriculture, maintain protected areas and exclude them from use, keeping extensively cultivated agricultural areas intact, limited forest residue removal, compensation for additional forest fellings (like protected areas and deadwood). These criteria implicitly present the biodiversity definition.

The report and designed criteria specifically address farmland or agro-biodiversity. The study states that intensification among other pressures negatively affects this type of biodiversity. Also farm abandonement will lead to the loss of characteristic agricultural landscapes that contain high nature value farmland (HNVs). Another used indicator or agro-biodiversity is crop diversity. The report states that a more diverse land cover creates more habitats for species. Bioenergy crops such as perennial grasses and short rotation forestry can add to this habitat diversity. They conclude that new bioenergy crops and well managed grassland harvesting can help sustain or even promote biodiversity. In the case of intensively farmed bioenergy crops, biodiversity is lost, especially when it replaces extensive farming systems. The criteria therefore exclude this type of agricultural practices in these lands.

The area assumed to be available for bioenergy crops is dependent on the area that will be released from food and fodder production (mainly through liberalisation, increased productivity and high yield bioenergy crops). An environmentally compatible area of 0,2 million km^2 arable land will be available by 2030. Production shifts will take place, but the study does not take biodiversity effects outside Europe into account.

The European potential can only be safely exploited if incentives and safeguards are in place to ensure that the environmental criteria will be met. When this is not the case, significantly lower exploitation will lead to increased environmental pressures. Incentives should therefore be part of the Biomass Action plan.

Future vascular plant diversity under 4 scenarios (van Vuuren et al., 2006b)
For the Millennium Ecosystem Assessment (MEA, 2005), the impact of future environmental change on biodiversity was assessed by considering impacts that affect the extent of natural habitats. Biodiversity effects were derived from the theoretical relationship between area and species number, as a consequence of evolutionary speciation. This was done for 65 different homogeneous biogeographical units (biomes x ecoregions) separately. The effects are quantified as the number of species that may get extinct in future, both a local and global scales. The global indicator only allows for projections of species number loss. Increases in area will not result in higher numbers of species, as the time-scale is too short for evolutionary processes to occur. It can not consider the abundance of species. This approach can account

for human impacts that affect the extent of natural areas suitable for species belonging to the biogeographic unit. In this paper, habitat destruction and climate change were included.

The 4 different MA scenarios were used, including a scenario that focuses on environmental technology (Technogarden – TG; MA volume 2; see Carpenter et al., 2005). The TG-scenario limits temperature change to 1.9 degrees by 2100 by stabilization of CO_2 at 550 ppm. This is effectuated through measures such as rapid technological change aand a share of 40% for renewable energy sources. Global biofuel production in 2050 will amount to 280 MTon./year.

The TG-scenario leads to the lowest decline of natural habitat, given the combination of low population increase, high yields and low meat demands. Global plant diversity declines in all scenarios, with the lowest loss occurring in the Technogarden world (10% in 2050, and 13% in 2100, relative to 1995). An important result is that land-use change was the dominant factor over climate change, affecting biodiversity in the coming 50 years for most biomes (except for deserts and boreal ecosystems).

Effect of policy actions in the GBO2-outlook (CBD & MNP, 2007)
The Netherlands Environmental Assessment Agency was asked by the secretariat of the CBD to perform an outlook study on the effects of several policy actions on future biodiversity. This has resulted in a scenario study and a summary in the Global Biodiversity Outlook 2 (GBO2) Report (CBD, 2006). The climate change mitigation option in the GBO2 scenario study is based on the energy options assessment by (van Vuuren *et al.*, 2006a). In this study, the indicator mean abundance of the original species (MSA) was used to express global biodiversity loss. This aggregated indicator can be interpreted as a measure of “naturalness” or “intactness”, and can be disaggregated to regions, biomes and causes of loss (Scholes & Biggs, 2005).

A policy option was investigated that can be characterized as bio-energy intensive. The climate mitigation option consists of a scenario with a cost-effective portfolio of energy measures that will limit the rise in atmospheric CO2 to 450-550 ppm. This will effectuate a maximum global temperature rise of maximum 2 degrees by 2100. About a quarter of the future energy needs were projected to be fulfilled by bio-energy production (150 EJ in 2050). In the baseline, biofuel production required an area of about 0,2 x 10^6 km^2, mostly for woody biofuels. In the mitigation option, the required area rises to 6,2 x 10^6 km^2, of which 87% is used for woody biofuels (van Vuuren *et al.*, 2006a).

The climate mitigation option increased biodiversity loss on the short term, compared to the baseline scenario. However, on the longer term (2050 - 2100) the initial loss turned into biodiversity gains through avoided future climate change effects, which is a consequence of all of the included measures. There are several basic assumption (in fact areas of substantial uncertainty) in this analysis that lead to this conclusion:

- The biodiversity loss is expressed relative to a completely natural or restored situation.
- In the baseline scenario that serves as contrast for the climate mitigation option, the future increase in agricultural productivity (efficiency) was optimistic, which lead to limited additional land-use or even land abandoning in some areas.
- In the baseline, abandoned agricultural lands will restore to more or less natural situations.
- In the option, additional land conversion is necessary for the projected amount of bio-energy production and for carbon plantations. Abandoned lands are not sufficient for the ambitious goals with.
- Future climate change effects on biodiversity are substantial. This issue is also strongly related to the climate sensitivity to greenhouse gas emissions (i.e. 2,5 ºC increase as response to doubling CO2-eq concentrations). As a consequence, the effect of the climate mitigation option will also be substantial.
- Possible trade-offs of options to the aquatic environment were not included. These can be related to agricultural water use and food production through fishery.

Conclusions

This review of global scenario studies firstly shows that the most important human pressures for biodiversity are land-use changes and climate change. Both aspects should therefore be taken into account, as well on the short term as long term. Up to 2050, land-use changes will be dominant in global biodiversity decline, especially for grassland systems. Agricultural developments are primarily responsible for this effect. The effects of climate change are expected to be become more severe after 2050. A range of possible results are predicted for biodiversity effects due to climate change alone, showing the uncertainty of this issue. When regional scenarios and developments are used, possible trade-offs to other regions are left unconsidered. This is especially true where large scale agricultural abandonment takes place.

Table 5.5 Comparing scenario studies that include biodiversity effects. The bottom list includes projections on using bioenergy crops.

Study	***Amount of bioenergy / used crops***	***Used biodiversity indicators***	***Result***	***Remarks***
Not including bioenergy potentials				
Sala	- none -	Broadly defined – all organisms and scales, based on qualitative expert-opinion	Land-use change most important driver for biodiversity loss by 2100; next driver is climate change	Terrestrial biomes only, no aquatic biodiversity
Tilman	- none -	Area of natural ecosystems	Agricultural area expands to 45% of terrestrial surface by 2050. Natural area decreases strongly.	Trend analysis. To dampen this trend a new agricultural revolution is needed.
EUruralis 1	- none -	Hybrid approach : MSA – naturalness; RSR – relative species richness; organic farming.		Importance of intensification, land abandonment, restoration and HNVs.
Explicitly including bioenergy potentials				
Wackernagel	All energy from virtual crops and forests.	EF- Ecological Footprint	Total virtual land-use equals 1.2 times the bioproductive area in 2000. For energy alone, this is 0.6.	Virtual land-use can implicitly be seen as using bioenergy crops
WWF	- idem -	- idem -	In 2050, 1.8 to 2.2 of biocapacity is used. About half is for energy needs.	- idem -
EEA	12,6 EJ by 2030 can be produced in EU-25 / perennials and double cropping, short rotation forestry, crop and habitat diversity	Hybrid approach: Protected areas, extensive farming - HNV farmland, forest deadwood, soil fertility, crop diversity.	15% can be potentially provided within Europe under (regional) environmental constraints.	Abandoned agricultural land important for energy crops. Biodiversity loss through shifts in production regions not taken into account ('elsewhere').
Van Vuuren – MEA	280 MT per year by 2050 / crops unspecified	Number of extinct species	10% global loss in 2050	Terrestrial plants only
Ten Brink - GBO2-Outlook	150 EJ per year by 2050 / mostly woody biofuels	MSA – naturalness	1% more global loss than baseline loss of 8%	Loss is a balance between short-term area loss and reduced climate change on the long-term. No freshwater and marine biodiversity.

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6 Demand-side models

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6.1 Summary Demand-side models

6.1.1 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. This type of questions is generally studied using energy-economics or energy-system models. We analysed these models on the role of biomass in power generation, biofuels, heating and biomaterials, and the assumptions behind these roles. Note that almost these demand-side models also need to make assumptions on availability and cost of biomass, in order to compare the option's competitiveness with other (possibly climate-neutral) options. As such, it is not possible to make a clear-cut distinction between biomass supply assessments and studies on its application.

6.1.2 The ideal study

The ideal study has at least the following characteristics:

1. It takes the fundamentals of energy demand into account, i.e. population growth, GDP development, and relates global energy demand to these factors in a way that deals with the possibility of improving energy efficiency by technological and other innovations.
2. It includes all energy-related sectors and applications of feedstock, i.e. power generation, transport, heating (domestic as well as industrial) as well as feedstock applications for materials.
3. It encloses all options for supplying energy-related services, i.e. conventional and advanced fossil options and all kinds of renewable options.
4. It fills in projected energy demand per sector by economic rules, i.e. by choosing least-cost options at given (external) constraints. Such constrains can be specific policies or explicit CO_2 reduction targets, but other constraints will be inherent to the energy system (e.g. no unlimited introduction of intermittent power generation technologies without addressing costs for net balancing measures).
5. Costs of the different energy supply options are assessed with dynamic and (e.g. as for biomass applications) interrelated cost-supply curves.
6. These curves also take into account technological learning of innovative options in particular.
7. It contains extensive analysis of the sensitivity of the outcomes to different scenarios or differences in the key assumptions on e.g. costs.

6.1.3 Review of studies

For this part, we reviewed six global studies, two for the EU and one for the Dutch level. The extent to which the aspects of the 'ideal' study are included, is summarized in table 6.S1

Table 6.S1 Comparison of surveyed studies

	Geog coverage	1. Demand[1]	2. Sector coverage[2]	3. Supply options[3]	4. Metho-dology[4]	5. Cost assessment[5]	6. Learning	7. Sensitivity analysis[6]
EPPA	Global	PGI	Pht	FCNBR	G	F	No	No
GET	Global	PGI	PhT	FCNBR	L	F	Simplified	Yes
WEM	Global	PGI	PhT	FCNBR	E	c	Yes	No
Timer	Global	PGI	PHT	FCNBR				No
Message	Global	PGI	pht	FCNBR		F	No	No
BEAP	Global	PGI	PHTM	FCNB	L	F	Yes	No
Primes	EU25	PGI	PHT	FCNBR	E	c	Yes	No
Markal	EU15	PGI	PHT	FCNBR	L	F	Yes	No
PGG	NL	PGI	PHTM	FB	T	No	No	No

[1] Taken into account: P: Population growth; G: GDP growth; I: Energy efficiency

[2] Taken into account: P: power generation; H: heat, T: transportation; M: materials. Capitals: cost and output specified for each option, lower case: costs or output details lacking.

[3] Taken into account: F: fossil options; C: fossil options with CCS; N: nuclear; B: biomass; R: other renewables

[4] G: General equilibrium model (economic); L: least-cost (linear programming); E: energy balancing; T: technical potential assessment

[5] F: fixed costs, e.g. a mark-up factor; C: cost-supply curves; U: unclear. Capital: specified in detail, c: data or details lacking

6.1.4 Resulting data for key parameters

An overview of the demand for biomass as produced by the different global studies is summarized in Figure 6.S1

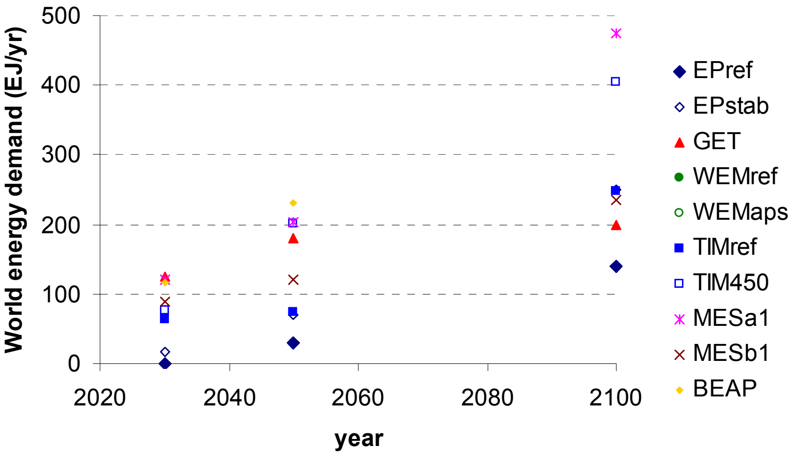

Figure 6.S1 Biomass use in the different global energy scenarios.

Much more than in total energy demand, there is a wide spread in biomass use, in absolute and in relative terms. Differences in accounting for traditional biomass may be one of the factors causing the spread. As could be expected, mostly the more climate-ambitious or CO_2-stressed scenarios show a higher biomass demand than their corresponding reference or baseline scenarios (with an exception of the Message set). In GET, for example, the biomass share in 2100 is only limited by the model-imposed upper limit of 200 EJ/yr.

Concerning the application of biomass in different sectors, Figure 6.S1gives an overview. Much of the differences between the studies in biomass allocation seems to be related to differences in the cost and introduction rate of competing conventional fossil, bio-based and other renewable and/or climate-neutral fossil options. Generally, the power generation sector has relatively many climate-neutral options competing with biomass: other renewables, but also fossil options with carbon capture and sequestration (CCS). The ratios between assumed cost and supply potentials per option directly affect the competitiveness of biomass options. For the transportation sector, biofuels essentially have one competing climate-neutral option: the hydrogen-fuelled fuel cell, which can be either fed by hydrogen from renewables or from fossil resources with CCS. Especially for such relatively innovative options with a development trajectory ahead, cost estimations vary widely among the studies, directly leading to differences in biomass competitiveness in the sector.

Another factor influencing the application of biomass is differences in policy assumptions, particularly in the way climate and renewables policies are deployed. If this is done by a generic (and modest) CO_2 price, biomass will mostly be allocated to stationary applications such as heat and power. With a more stringent CO_2 policy, or when specific subtargets are defined for each sector, biomass may be allocated more to transportation, since this sector hardly has any other climate-neutral options, while the other sectors do.

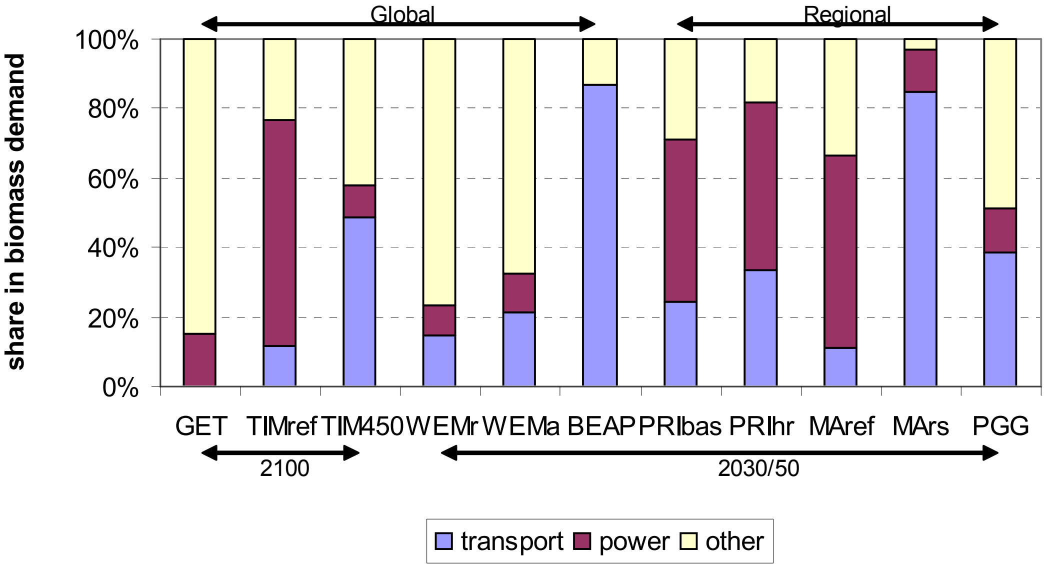

Figure 6.S2 Shares of power, biofuel and other applications in the different global and regional scenarios, sorted in increasing order of power share. EPPA is omitted, since the allocation between transport and other applications is not clear.

6.1.5 Conclusions

Projects of demand for biomass by 2100 indicate that we should think of amounts in terms of 100s of EJ, with a minimum of 150 EJ (in a conservative reference scenario without any climate policy) and a maximum of more than 400 EJ (in a biomass-intensive scenario with active climate policy). 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.

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.
- Almost all studies work with relatively constant costs for biomass, while it can be expected that this feedstock will generally show increasing cost with increasing demand.
- 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 learning.

Finally, it should be noted that a fundamental comparison of models and studies should take place on the level of basic input data and assumptions. For such a comparison, a literature survey seems to be hardly sufficient since such detailed data are hardly spread into the public domain. It would probably require more in-depth research, e.g. by personal interviews with the key responsible modellers.

6.2 Introduction

In order to put the assessment of biomass potentials and their interrelations with other land-claiming functions into perspective, this part of the project analyses assessments of future energy demand development and the foreseen role of biomass therein. With respect to the latter, we focus on the allocation of biomass to different applications and the underlying assumptions behind all this. This type of questions is generally studied using energy-economics or energy-system models. In contrast to models and studies that aim to assess the potential supply of biomass discussed in Chapter 2, the methodologies discussed in this section all focus demand-side dynamics. Note, however, that almost all demand-side models also need to make assumptions on availability and cost of biomass, in order to compare the option's competitiveness with other (possibly climate-neutral) options. As such, it is not possible to make a clear-cut distinction between biomass supply and use.

The ideal study
The ideal study has at least the following characteristics:
1. It takes the fundamentals of energy demand into account, i.e. population growth, GDP development, and relates global energy demand to these factors in a way that deals with the possibility of improving energy efficiency by technological and other innovations.
2. It includes all energy-related sectors and applications of feedstock, i.e. power generation, transport, heating (domestic as well as industrial) as well as feedstock applications for materials.
3. It encloses all options for supplying energy-related services, i.e. conventional and advanced fossil options and all kinds of renewable options.
4. It fills in projected energy demand per sector by economic rules, i.e. by choosing least-cost options at given (external) constraints. Such constrains can be specific policies or explicit CO_2 reduction targets, but other constraints will be inherent to the energy system (e.g. no unlimited introduction of intermittent power generation technologies without addressing costs for net balancing measures).
5. Costs of the different energy supply options are assessed with dynamic and (e.g. as for biomass applications) interrelated cost-supply curves.
6. These curves also take into account technological learning of innovative options in particular.
7. It contains extensive analysis of the sensitivity of the outcomes to different scenarios or differences in the key assumptions on e.g. costs.

6.3 Overview of the assessed models

As most assessments in the WAB project have a global scale, the accent is on global energy models. However, since it may also be useful to have more specific information on the EU context, we also analysed some scenarios on the future role of biomass in the EU, and one study specifically for the Netherlands. Obviously, models are used in specific studies and are driven by assumptions that are relevant in the context of that study. In the discussion here we have selected a typical study for each model. Models and studies analysed were:

Global models:

- EPPA (Emissions Prediction and Policy Analysis) is the energy submodel attached to IGSM, an integrated assessment model for the analysis of climate change and climate policy options. The model was developed at MIT. Two scenarios were analysed, a reference (EPref) and a CO2 stabilisation scenario (EPstab).
- GET, developed at Chalmers University of Technology, determines the least-cost energy mix meeting a specified demand for energy, given an atmospheric CO2 stabilisation standard.
- The WEM (World Energy Model) of IEA is the basis of the organisation’s World Energy Outlook. It mimics the functioning of energy markets, taking into account the impacts of existing and/or new climate-oriented policies. The reference and policy scenarios are included in the analysis (WEMref and WEMaps, respectively).
- Timer (Targets-Image energy Regional model) is the energy submodel in IMAGE, another integrated assessment model on climate change. It was developed at RIVM/MNP.
- Message is the IIASA integrated assessment model, from the broad set of SRES scenarios by this model, we selected the A1B and B1 scenarios to provide a certain band with.
- BEAP (Biomass Environmental Assessment Program) was developed at the Japanese National Institute for Environmental Studies, using most technology data from the EU BRED project (Biomass for greenhouse gas emission REDuction), with ECN as a key contributor. In this study, we include the global (climate) policy scenario.

Regional models:

- Primes, developed at the National Technical University of Athens, is one of the most commonly used models for the European Union. For example, it is often used for ex ante impact assessments of EU policies. It is a behaviour- and price-driven partial equilibrium model of the EU energy system. Here, we include the 2006 baseline scenario (PRIbas) and the 2006 High renewables plus energy efficiency scenario (PRIhr)
- The Markal (MARKet Allocation) model developed at ECN is a family of dynamic bottom-up energy system models, mostly based on linear programming. Currently, it covers the EU15 (Western Europe). The scenarios as a baseline (MAref) and a 20% RES scenario (MArs)
- For the national context of the Netherlands, we also include a study for the Dutch Green Feedstock Platform (PGG). This study analyses the technical feasibility of biobased feedstock introduction in different parts of the energy economy (power, transport, domestic and industrial heating, and material applications). For example, it takes depreciation and replacement rates of current fossil-based capacities into account, and can therefore be considered a technical upper limit of biomass use by 2020.

Key information on the scenario studies and applied models are summarised in Annex 4.

The studies were analysed on:

- Key assumptions in population, GDP and primary energy demand (Annex 5);
- The biomass share in the supply of total primary energy demand, and its applications in power, transport or other sectors (Annex 6);
- Assumptions on policies (Annex 7);
- Assumptions (if available) on technologies and their costs (Annex 8, 9 and 10).

On the basis of this analysis, we can indicate the extent to which the aspects of the ‘ideal’ study are included. This is summarized in Table 6.1

Table 6.1 Comparison of surveyed studies

	Geog coverage	1. Demand[1]	2. Sector coverage[2]	3. Supply options[3]	4. Metho-dology[4]	5. Cost assessment[5]	6. Learning	7. Sensitivity analysis[6]
EPPA	Global	PGI	Pht	FCNBR	G	F	No	No
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Timer	Global	PGI	PHT	FCNBR				No
Message	Global	PGI	pht	FCNBR		F	No	No
BEAP	Global	PGI	PHTM	FCNB	L	F	Yes	No
Primes	EU25	PGI	PHT	FCNBR	E	c	Yes	No
Markal	EU15	PGI	PHT	FCNBR	L	F	Yes	No
PGG	NL	PGI	PHTM	FB	T	No	No	No

[1] Taken into account: P: Population growth; G: GDP growth; I: Energy efficiency

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[3] Taken into account: F: fossil options; C: fossil options with CCS; N: nuclear; B: biomass; R: other renewables

[4] G: General equilibrium model (economic); L: least-cost (linear programming); E: energy balancing; T: technical potential assessment

[5] F: fixed costs, e.g. a mark-up factor; C: cost-supply curves; U: unclear. Capital: specified in detail, c: data or details lacking

In the next sections, we shortly dwell on the key outcomes of the different studies, in terms basic parameters including energy demand (section 6.4), the biomass share (section 6.5) and the allocation of biomass (section 6.6. As far as possible, we try to attribute differences between scenarios and models to their technical, policy and/or other assumptions.

6.4 Basic parameters: population, GDP, and global energy demand

Concerning population, the assessed studies are fairly consistent with each other. On population growth, most scenarios use UN data. Depending on the specific scenarios and the year of the source used, 2100 World population varies between 7 and 10 Billion people.

Concerning GDP development, EPPA, WEM and the Message A1b scenario are very close to each other. The Message B1 scenario clearly has a lower economic growth rate, which may be due to its different storyline compared to A1b by the assumed relationships between economic growth and energy demand (efforts needed to reach a lower energy demand lead to less growth and/or lower growth inducing lower energy demand).

Projected global energy demands are summarised in Figure 6.1. Apart from the Message A1b scenario, all studies lie within a range of a factor 2. The Message A1b could be expected to be high in energy demand, since its SRES storyline is an ambitious, market-driven globalisation without climate-driven limitations to energy use. The scenarios with an explicit cap on CO_2 emissions (such as GET, EPstab, BEAP and MESb1) have a lower primary energy demand than reference scenarios such as EPref, which are free of any CO_2 limitation. While policy-induced efficiency improvements are part of the explanation of this, in addition, most of the studies mentioned also include less energy demand growth in their baseline scenarios. The policy-induced part is likely to be caused by a combination of climate-policy induced energy efficiency improvement, and a lower GDP growth rate. In GET, in which economic growth is not a factor in the model, the former mechanism probably dominates, in the two Message scenarios, both mechanisms are probably in action.

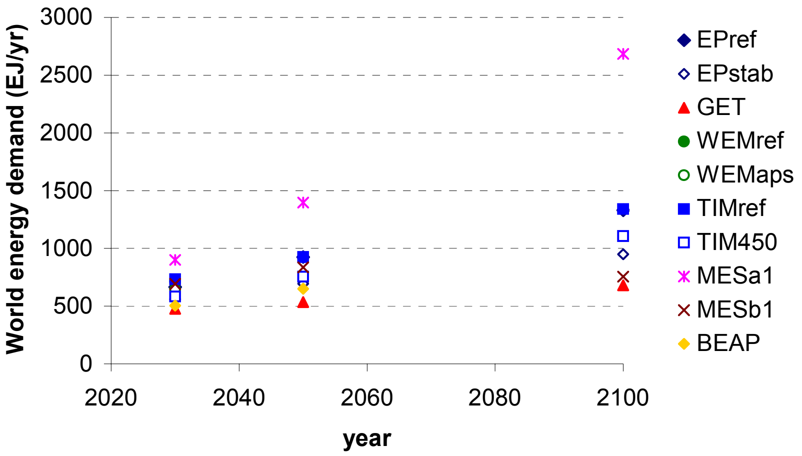

Figure 6.1 World primary energy demand as indicated in the different scenario studies.

Concerning regional models, energy demand in Primes and Markal are of a similar order of magnitude. In Primes, however, a High Renewables scenario leads to significantly stronger reduction in energy demand than in the Markal renewables scenario. This may either be due to differences in technology assumptions, or in the corresponding policy packages. However, since both models do not clearly specify their technology assumptions, this is hard to verify.

6.5 Biomass demand

6.5.1 Primary biomass demand

The primary demand for biomass in the different global models is given in fig 6.1. Much more than in total energy demand, there is a wide spread in biomass use, in absolute and in relative terms. Note that most models do not clearly specify between traditional biomass (for e.g. domestic heating and cooking) and advanced biomass (for e.g. power generation or biofuels). Differences in accounting for traditional biomass may be one of the factors causing the spread. Some observations:

- As in energy demand, Message A1b gives the highest figure on biomass demand as well, again probably due to the energy-intensive storyline of this scenario. Since climate policy is not part of this scenario, the high use of biomass is induced by high energy demand and assumed limitations in maximum fossil supplies. Strikingly, the Message scenarios have mutually different amounts of biomass, but the shares in their respective total demands are quite identical.
- Some other scenarios also show high biomass demand, especially when we also take the scenarios that do not run to 2100 into account). For example, BEAP shows a very ambitious 2050 biomass demand.
- As could be expected, mostly the more climate-ambitious or CO2-stressed scenarios show a higher biomass demand than their corresponding reference or baseline scenarios (with an exception of the Message set). In GET, for example, the biomass share in 2100 is only limited by the model-imposed upper limit of 200 EJ/yr.
- On the other hand, the two WEM scenarios hardly show any difference in biomass demand (the points overlap so strongly in the figure that they are hardly discernable). Apparently, the Alternative Policy Scenario does not contain policies that significantly increase demand for biomass, of the model includes some strong techno-economic limitations.

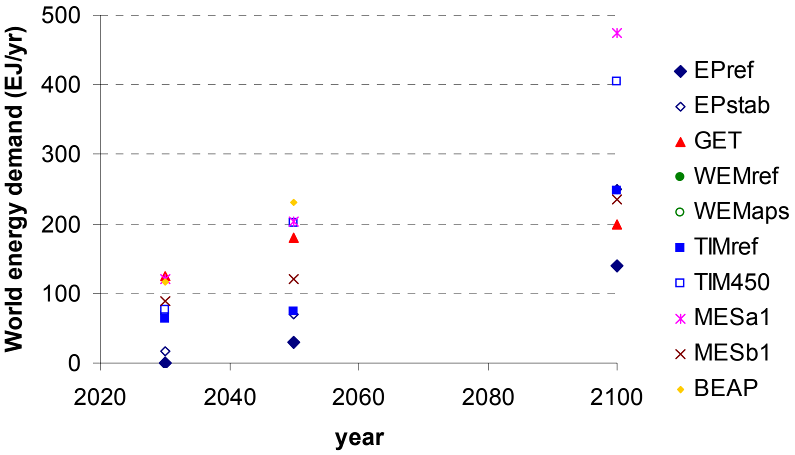

Figure 6.2 Biomass use in the different global energy scenarios

6.5.2 Biomass share in total demand

The relative shares of biomass in total demand are illustrated in Figure 6.3 (2030 data), for the global as well as the regional scenarios. This share varies from 0% in EPref (and 3% in the accompanying stabilisation scenario) to more than 25% in GET and 30% in the PGG scenario.

- Concerning the regional models, it is striking that the impact of a more ambitious renewables scenario has greatly comparable impacts in Primes as well as in Markal (shares increasing from ca 10% to ca 20%).
- The PGG scenario has the highest biomass share. It should be noted, however, that this scenario is mostly based on an analysis of the maximum technically feasible biomass demand (limited by e.g. the replacement pace of existing fossil-based capacity), with only limited consideration of economic attractiveness. Therefore, this scenario can best be regarded an estimation of the maximum demand.

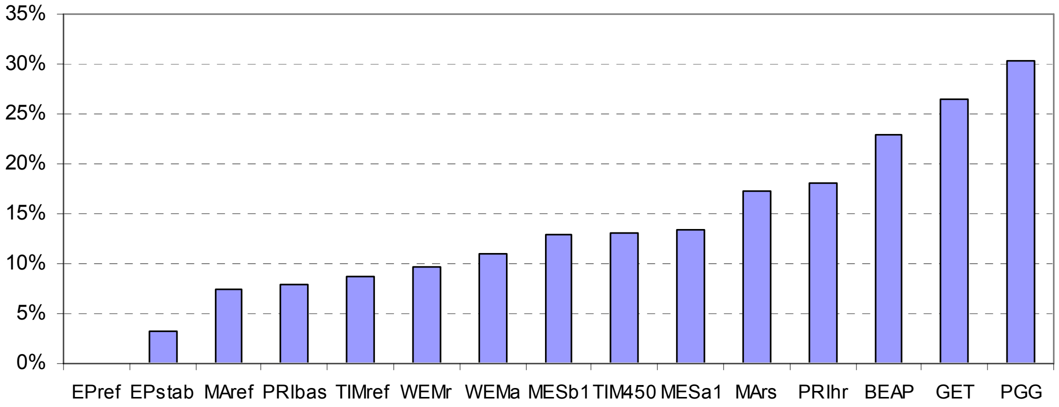

Figure 6.3 Biomass shares in total energy supply, for the global and regional scenarios.

6.5.3 Assumptions on biomass availability and cost

In order to compare these mainly demand-driven models to the studies on supply potential, the assumptions on availability and cost of biomass feedstock are also relevant. In most models, there is no clearly specified upper limit on the availability of biomass. Only GET assumes that maximally 200 EJ/yr of biomass feedstock can be used, at a fixed cost of 3 $/GJ. BEAP is the other model with fixed biomass feedstock cost of 2.5 $/GJ/. Most other models seem to make use of more dynamic cost-supply curve approaches, which however are not made explicit in terms of numbers. EPPA's land allocation basis IGSM simulates markets for food, bioenergy and other land-using functions, which compete for the available (agricultural) land area. Via this mechanism, the upper limit of biomass availability depends on e.g. population growth and demand for food. A comparable line of reasoning probably applies to the Message models, since this is also an integrated assessment model with a strong land use assessment component. According to Grahn et al (2006), BEAP also dynamically limits biomass availability by land and corresponding biomass prices. In this context, WEM refers to dynamic cost-resource curves. However, it is not clear to what extent biomass supply limits influence biobased options at ambitious shares.

6.6 Biomass applications

Figure 6.4 summarises the allocation of biomass of different applications. Note that the graph depicts the relative shares for the end year of each scenario (which varies between the models). Most numbers refer to a 2030/2050 situation; of the 2100 scenarios only the literature sources of GET and Timer provide specific biomass allocations.

While many studies are not very specific in their techno-economic assumptions leading to these differences, the authors of the BEAP and GET models have jointly analysed the key factors leading to the different biomass allocations in their models, while their general methodologies are quite similar (Grahn et al, submitted). The authors conclude that both models behave similarly if no CO_2 constraints or limited constraints are applied (in terms of emission caps and/or carbon taxes): most biomass demand is generated in stationary sectors, and transport remains fossil-based since bio-based options cannot compete in this sector. However, in more CO_2-stringent scenarios, the transportation sector cannot remain unchanged. In BEAP, biomass is then allocated to transport, while it is the only available option for the sector; other climate-neutral options (partially) take over the role of biomass in power and heat. GET, however, includes fossil-based carbon-neutral hydrogen fuel cells for transport in its technology portfolio. In the model, this option is assumed to be more cost-effective than biofuels; therefore transport turns to hydrogen while biomass remains allocated to stationary applications. TIMER behaves like BEAP: although H_2 is available as an option, the model assumes that H_2 is not likely to become a competitive option to biofuels in transport.

This type of mechanism may explain some more differences among the studies. However, it was not possible to fully analyse this, since many publications studied do not provide specific information on the underlying techno-economic assumptions. But in Markal, for example, comparable effects can be observed. In the Markal RS scenario, specific policies for transport are introduced, and the (year 2030) costs of hydrogen/FC technologies are assumed to be higher than those of biofuel options. Primes also includes specific sub-targets for transportation, thereby forcing the sector away from fossil options.

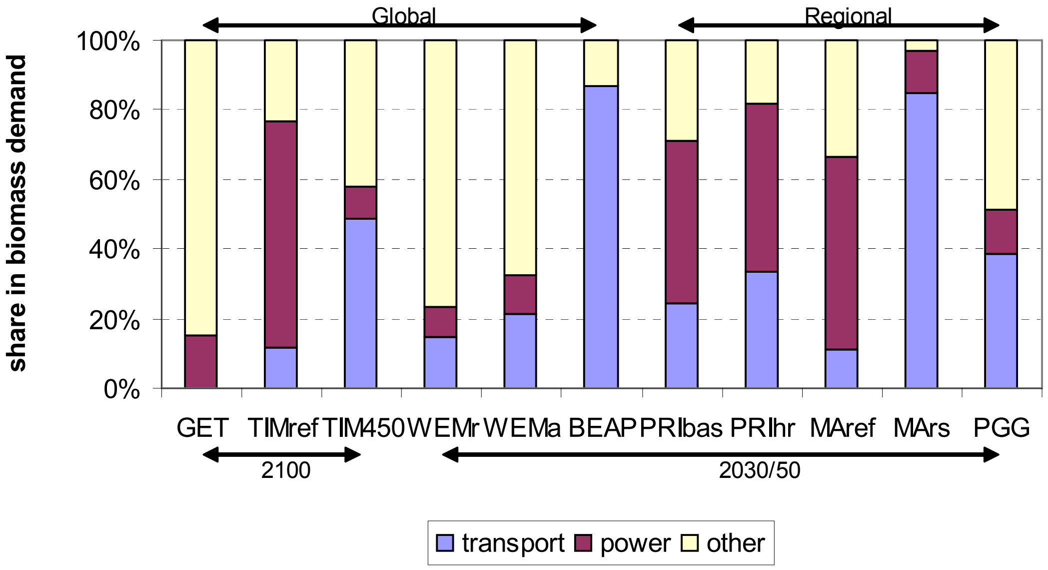

Figure 6.4 Shares of power, biofuel and other applications in the different global and regional scenarios, sorted in increasing order of power share. EPPA is omitted, since the allocation between transport and other applications is not clear.

EPPA assumes structural higher costs for biomass-based power generation and transportation fuel production, and for power generation this mark-up factor is also higher than the mark-up of competing climate-neutral options (especially for fossil options with CCS). The high CO_2 prices this model has in later decades force the system to move away from conventional fossil options. In the power sector, however, there are other climate-neutral options that are assumed to be more competitive than bio-based options. It is not entirely clear to which extent biomass enters transportation, since the model's results do not discern between biomass use as biofuel or in heating. However, Paltsev et al. (2005) and Clarke et al. (2006) explicitly mention an increase in biomass application for transportation fuels.

From the data in Figure 6.4, a systematic difference between 2030/50 and 2100 scenario can not be observed. In principle, the 2100 situation may differ from the more nearby scenarios in two respects. Most climate-active scenarios, such as TIM450, GET, and EPstab apply time-dependent (and increasingly stringent) emission limitations and corresponding CO_2 prices. This would increase the urgency of emissions in the transportation sector over time. Secondly, many scenarios probably apply increasing oil prices over time, especially in the period after 2050. Again, this increases the urgency to shift to (at least) oil-free and (possibly) climate-neutral options for transport. However, in a scenario such as BEAP, biomass is already dominantly applied transport in 2040. For regional scenarios such as PRIhr and MArs, the share of biomass in transport is mostly induced by sector-specific targets and policies.

Only two studies specify the demand for biomass from the non-energy sectors: BEAP and the PGG study. Both studies assess potentials for biomass demand for materials like wood and paper, but also as feedstock in steel or organic chemical production. BEAP indicates a global biomass-to-non-energy demand of ca 17 EJ by 2050 (7% of total biomass demand); the Dutch PGG study assesses that ca 200 PJ biomass demand for non-energy purposes could be generated in this country 22% of total biomass demand). Note that PGG only assesses technical potentials taking into account replacement rates of existing technology capacity, while BEAP optimises total energy and feedstock application to overall least cost. Therefore, the 200 PJ should be considered a maximum demand specific for the Dutch context, while the BEAP figure give an order of magnitude of demand when competing options are also taken into account.

In short, the differences in specific allocation of biomass between different applications seem to depend on two dominant factors:

- Differences in techno-economic assumptions for competing conventional fossil, bio-based and other renewable and/or climate-neutral fossil options. Especially for relatively innovative options with still a development trajectory ahead, cost estimations may vary widely.
- Differences in policy assumptions, particularly in the way climate and renewables policies are deployed. If this is done by a generic and modest CO2 price, biomass will mostly be allocated to stationary applications such as heat and power. With a more stringent CO2 policy, or when specific subtargets are defined for each sector, biomass may be allocated more to transportation, since this sector hardly has any other climate-neutral options, while the other sectors do.

6.7 Conclusions

Projects of demand for biomass by 2100 indicate that we should think of amounts in terms of 100s of EJ, with a minimum of 150 EJ (in a conservative reference scenario without any climate policy) and a maximum of more than 400 EJ (in a biomass-intensive scenario with active climate policy). 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.

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.
- Almost all studies work with relatively constant costs for biomass, while it can be expected that this feedstock will generally show increasing cost with increasing demand.
- 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 learning.

Finally, it should be noted that a fundamental comparison of models and studies should take place on the level of basic input data and assumptions. For such a comparison, a literature survey seems to be hardly sufficient since such detailed data are hardly spread into the public domain. It would probably require more in-depth research, e.g. by personal interviews with the key responsible modelers.

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7 Agricultural economics

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7.1 Summary of Agricultural economics

7.1.1 Introduction

In this paper we discuss some studies concerning the economics of biomass for biofuels, determining the availability of biomass for biofuels. In the assessment of the different kind of studies we will focus on the studies which aim to assess the total production of biomass for biofuels. We will not take into account the studies which calculate cost prices for the individual farmer.

Economics occupies a special position in the study, because it integrates costs and values. Ideally, it shows “what the society wants”. Therefore, the agro-economic models are based on agri-technical coefficients, restrictions (environmental, technical), other uses for labour and capital, oil prices etc. The input is therefore based on discussion of the other WAB-parts.

7.1.2 The Ideal Study

The ideal study that determines the production of biofuels – produced by farmers - compares the costs of production with the yield for several crops which the farmer is able to produce. The study compares the net-return for each crop for each farmer and then the attractiveness of the biomass “appears”. Furthermore the ideal study assesses the production of biomass produced by *all* individual actors. This step requires something more. When a group of farmers decides to grow a new crop in stead of an “old” crop, something “happens” which prices of crops. The market will search for a new equilibrium in supply and demand, resulting in (new) prices. The prices for the “new” crop might decrease, while the prices of the “old” crop (less supply, same demand) might increase. Furthermore, we often see by-products as a result from the processing of biomass to biofuels. These by-products have to find a place in the market. Producing a lot of by products might have (negative) effects on prices and thus feasibility.

An economic assessment requires dealing with supply and demand of food, feed and fuel. Supply and demand have to be fed by all relevant driving forces. A higher demand of bio fuels has consequences for prices for food and feed. These consequences will lead to a new equilibrium for biomass commodities. Consequently, not only the assumptions concerning driving forces have to be assessed; the most decisive question is whether the principle of finding a new market equilibrium with new prices has been part of the study.

Summarized, the ideal study takes into account the effects on prices, production, markets of all other crops. The ideal study 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 competing claims of food, feed and fuel on production factors in order to estimate a real economic feasible production of biomass for fuel.

7.1.3 Review of studies

Within this study some economic studies have been assessed. First comment is that the agro-economic models which deal with this agro-economic principle are just starting with the implementation of the biofuel directive and biofuel-options. 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 up to now, 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. Therefore, there is a lot of work to do!

In the literature we find a few studies which we have been discussed:
- “POLYSYS-studies” developed by the Agricultural Policy Analysis Center, Department of Agricultural Economics and Rural Sociology, The University of Tennessee
- The study “Agricultural Market impacts of future growth in the production of biofuels” conducted by the OECD
- FAPRI
- International Ethanol Model, developed by the Center for Agricultural and Rural Development of the Iowa State University
- SCENAR 2020 and
- EU-RURALIS

It’s clear from these studies that it’s critical to understand the dynamics of the relationship between biofuel and agricultural markets. The studies illustrate that the discussions about the fuel sources need to take into consideration of impacts on the world agricultural markets. The price of corn and oilseeds is impacted by and impacts not only fuel production, but also the prices of other crops in the world, area allocation and the world crop markets and how other countries respond to the price change. The impact also extends to the livestock sector through (higher) feed prices. One sees the influence of the biofuel policy on prices of food and feed already: prices increase (rapidly). On short term these consequences can be seen; the consequences on longer term are not assessed, yet.

7.1.4 Resulting data for key parameters

The most important points of interest in working out the available biomass for biofuel is *the concept* by which the biomass has been estimated. As said before, it’s necessary to deal (a) with competing on crop-scale on farmers-scale and to be aware of (b) effects on prices on fuel, feed and food. However, the estimation of key parameters is another point of attention.

The driving forces behind agro-production are: the demography, the global change (environment), the political administrative regime, the macro-economic, the agri-technology and the 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. There is the most actual input for the driving forces, determining supply and demand.

It’s advisable to be aware of the fact that those driving forces influenced by a lot of developments worldwide. These development are not static, they are dynamic. Therefore, it’s recommendable to work with scenarios. The economic studies that have been carried out often formulate scenarios and for each scenario consequences are determined. Almost all economic studies assess the consequences of different scenarios. Economic studies do not predict or give a prognosis, but they try to show the possible effects of changing policy. Therefore they always work with the principle “what .. if ….”. Driving forces and scenarios form the focus of the EU-project Scenar2020.

7.1.5 Conclusions

- 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. 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 residues and (b) the production of bio-energy often leads to residues. Residues are primary and secondary residues (from agriculture respectively food processing). Therefore those markets have a relation which can not be neglected! The ideal study is aware of those relations.

- The agro-economic studies that have been carried out often deal with the agricultural land and do not take into account the forestry land.
- The agro-economic studies are just starting with the implementation of the biofuel options in their model. The studies that have been carried out illustrate the effects of the demand of bio-energy on agricultural prices.
- The agro-economic studies which have been carried out do not deal with the second generation biofuels, made from by products.
- The studies which have been carried out illustrate the necessity of being aware of the competition and interactions between agricultural markets. The production of biofuels has effects on prices of feed and food. Those effects have to be taken into account in order to make a more realistic picture of available biomass for biofuel.
- The driving forces behind agro-production are: the demography, the global change (environment), the political administrative regime, the macro-economic, the agritechnology and the changes in value in society, consumer concerns and behaviour.
- The key-parameters for these driving forces vary, are not static. Therefore, ideally one must work out several scenarios. The worldwide databases of FAO, OECD, EU etc. are the most suitable as a base for the scenario's.

7.2 Introduction

In this chapter we discuss some studies concerning the economics of biomass for biofuels, determining the availability of biomass for biofuels. In the assessment of the different kind of studies we will focus on the studies which aim to estimate the total production of biomass for biofuels.
In the literature the following relevant studies were found, which we will discuss:

- "POLYSYS-studies" developed by the Agricultural Policy Analysis Center, Department of Agricultural Economics and Rural Sociology, The University of Tennessee
- The study "Agricultural Market impacts of future growth in the production of biofuels" conducted by the OECD
- FAPRI
- International Ethanol Model, developed by the Center for Agricultural and Rural Development of the Iowa State University
- SCENAR2020 and
- EU-RURALIS

One has to conclude that the economic assessment of biofuels within agro-economic studies is just at the beginning. Many agro-economic models are starting with the biofuel-case.

7.3 The ideal study

The ideal study that determines the production of biofuels – produced by farmers - compares the costs of production with the yield for several crops which the farmer is able to produce. The costs of production biomass for biofuels can be calculated in very different ways, and one has to be aware of those different calculation methods and the suitability for the purpose. In most studies the costs of using pesticides, fertilizers, energy etc. have been summed up, but the most decisive part of the calculation is how to deal with the costs of labour and capital. At which price have labour and capital to be valued? This is a case of assessing which "use" of labour and capital is the second best alternative. Therefore, a farmer will always compare the different opportunities for the "use" of labour and capital. He compares the net-returns of all the crops he is able to produce. Only when the biofuel gives the most attractive net-return he will choose for this crop[2]. This decision making aspect of farming is essential to give a "real" cost price, which

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[2] This is a simplification of the decision making process, while farmers take also other arguments into account.

tells something about the willingness to produce biomass for biofuels. This is an aspect which determines the outcome of the cost price in a very decisive way. In this paper we will not pay attention to this kind of studies as such, while the focus of the study is on a more aggregated level: all producers together. However, the base for the aggregated level can be found in the cost price studies.

Furthermore the ideal study assesses the production of biomass produced by all individual actors. As said before, we need the cost prices for each individual farmer in order to say something about the behaviour of a group of farmers. However, for assessing the behaviour of a group of farmers, we need more. When a group of farmers decides to grow a new crop in stead of an “old” crop, something happens which prices of crops. The market will search for a new equilibrium in supply and demand, resulting in (new) prices. The prices for the “new” crop might decrease, while the prices of the “old” crop (less supply, same demand) will increase. Furthermore, we often see residues as a result from the processing of biomass to biofuels. These residues have to find a place in the market. Producing a lot of by products might have (negative) effects on prices and thus feasibility. These effects are often not taken into account in the first and second type of studies, while the third category tries to be aware of this kind of economic mechanism.

Summarized, the ideal study takes into account the effects on prices, production, markets of all other crops. The competition with other markets (food, feed) – determining the output prices of competing markets and crops - is decisive for the economic feasibility of biofuels.

7.4 Review of studies

7.4.1 The POLYSYS-studies

Aim and focus of POLYSYS
The Policy Analysis System (POLYSYS) is a national simulation model of the US agriculture sector which can incorporate supply and demand and related modules to estimate agricultural production response resource use, price, income and environmental impacts of projected changes from an agricultural baseline. POLYSYS estimates crop production and supply at a disaggregated regional level, whereby the 48 contiguous states are subdivided into 305 geographic regions with relatively homogeneous production characteristics. POLYSYS is capable of estimating a wide range of policy alternatives and economic and environmental conditions. POLYSYS estimates supply- and price changes due to land shifts to biomass crops amid interactions with the major agricultural crops in the continental United States.

Methodology
POLYSYS is a modelling framework combining several models and databases, incorporating econometric, linear programming and process models, organized into crop supply, crop demand, livestock supply and demand and agricultural income modules. It is also able to deal with a variety of crop derivative products, crop rotations and management practices, perennial and biomass crops.

Land allocation among competing crops in each US-region is based on the maximization of expected returns where POLYSYS incorporates a prices expectation. While each region linear programming model is solved independently of the other regions, regional supply estimates are then aggregated across regions to obtain national crop supply estimates.

Each of the LP models is designed to maximize net returns above variable costs (including seed, fertilizer, pesticide, machinery services etc.) selecting from available crop enterprises and subject to policy and flexibility constraints. Flexibility constrains are designed such that the proportion of land allowed to shift from one crop to another or into or out of production, reflects the inelastic nature of agricultural supply.

POLYSYS also contains crop demand modules. The demand module estimates crop prices for the (twelve major) crops. The module also estimates demand utilization for each crop by use: food, feed, industrial, export and stock carryover where the sum of food, feed and industrial uses comprises domestic demand. In the national crop demand module, commodity demand is a function of price, cross-price shifters and non-price shifter variables. The module is also designed to work with a crop derivate products module (the by-products issue).

Geographic and time

- POLYSYS is focused on the US agriculture sector.
- The time-focus differs from study to study. Several studies have been conducted with the POLYSYS-model.

Scenarios and results

In De La Torre Ugarte and Ray (2000) some scenarios on biomass and bioenergy have been presented. For the scenario "1% of middle distillate fuels replaced by biodiesel (2007)" some results will be presented.

Table 7.1 Effects on cropland use for scenarios assuming "1% of middle distillate fuels replaced by biodiesel (2007)", in million acres

	Baseline	Scenario "1% replacement" /1	Change (%)
Corn	84,50	83,20	-1,5
Sorghum	11,20	11,20	0,0
Oats	4,70	4,70	0,0
Barley	7,10	7,10	0,0
Wheat	76,00	76,10	0,1
Soybeans	69,50	70,70	1,7
Cotton	14,00	13,90	-0,7
Rice	3,20	3,20	0,0
Sunflower	0,00	0,00	
Canola	0,00	0,10	
Soybean oil			
Soybean meal			

/1: "1% replacement": 1% of middle distillate fuels replaced by biodiesel
Source: De La Torre Ugarte and Ray, 2000

Table 7.2 Effects on crop prices for scenarios assuming "1% of middle distillate fuels replaced by bodiesel (2007)", in USD per unit

	Baseline	Scenario "1% replacement" /1	Change (%)
Corn	3,10	3,17	2,3
Sorghum	2,90	2,96	2,1
Oats	1,85	1,87	1,1
Barley	2,80	2,84	1,4
Wheat	4,45	4,47	0,4
Soybeans	7,25	7,32	1,0
Cotton	0,65	0,65	0,0
Rice	12,13	12,13	0,0
Sunflower	13,07	14,63	11,9
Canola	12,02	13,00	8,2
Soybean oil	0,27	0,37	37,7
Soybean meal	236,50	207,20	-12,4

/1: "1% replacement": 1% of middle distillate fuels replaced by biodiesel
Source: De La Torre Ugarte and Ray, 2000

One can conclude that the increase in biodiesel use of vegetable oil results in larger plantings of soybeans and higher prices of soybeans at national level. The small increase in the price of soybeans is due to the drops in the price of meal (by product of soybean crushing, used in the

7.4.2 OECD-studies

Aim and focus

The OECD has conducted the study “Agricultural Market impacts of future growth in the production of biofuels” which aims to look at the economics of biofuel production and the likely impacts of an expected growth in biofuel-related demand for agricultural products on commodity markets. The study describes the economics and policy in biofuel markets. The study brings together available information on production technologies, costs and policy measures in major biofuel producing countries. Additionally based on assumptions where data are missing, production costs have been calculated for the year 2004 and compared across countries and production processes as well as with oil-based fuel prices. It shows the relative competitiveness of biofuel production. Also the impacts on agricultural markets have been analysed.

Methodology

The impacts on the agricultural markets have been analysed by using the (OECD) partial equilibrium model for “temperate zone agricultural commodities” (called Aglink) in connection with the FAO-counterpart (Cosimo) and the OECD World Sugar Model. It’s called Aglink/Cosimo/Sugar model.

The analysis of the implications for agricultural markets of an expected growth in biofuel production as well as of higher crude oil prices is based on a quantitative model and a set of baseline projections generated with this model. Aglink is a (a) recursive-dynamic (b) multi-region (c) multi-commodity (d) partial equilibrium model of regional and world markets for temperate-zone agricultural products. It has been extended by the Cosimo model which focuses on the developing world. In addition, it has been merged with the existing OECD World Sugar model. A set of baseline projections – based on the OECD-FAO Agricultural Outlook 2005-2014 – which represent a plausible scenario of the future development of supply, demand, prices and trade of agricultural commodities world wide and for international markets over a ten year horizon under a set of assumptions. These assumptions cover macro-economic development, agricultural policies and normal weather patterns. They should not be seen as market forecasts, but the represent a useful basis for examining the market impacts resulting from changes in some of the driving factors.

One should mention that the OECD-study doesn’t take trade in biofuels into account. The model assumes the growth in biofuel consumption to be linked to an equivalent growth in biofuel production within the same country or region.

Scenarios and results

The OECD has formulated three scenarios:

- A constant biofuels scenario including an exogenous assumption of biofuel production, crop demand for biofuels and by product generation at their 2004 level throughout the projection period (of ten years). It’s a no-change scenario with respect to biofuels.
- The policy-target scenario: the scenario that includes growth of biofuel quantities in line with the officially stated goals given baseline prices for agricultural commodities.
- The high oil price scenario: the scenario in which the oil price is assumed to be high: 60 USD per barrel from 2005. This high price will affect the agricultural markets in two ways. First it will increase the production costs of agricultural commodities. Secondly it will increase the demand for biofuels.

Results:

- The study gives the current production costs for different sources of biomass for different producing regions[3].
- The study shows the area requirements for a given share of domestic transport fuel consumption[4].
- The study shows the effects for different scenario’s:
    - The additional demand for agricultural commodities is likely to substantially affect the outlook for their markets. The major producers of biofuels – Brazil, the United States, the

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[3] These results will not be discussed in this paper, while they do not focus on the questions to be answered in this study.

[4] These results will not be discussed in this paper, while they do not focus on the questions to be answered in this study.

European Union and Canada are covered explicitly in this analysis – are expected to significantly reduce their exports of the respective feedstock commodities or to increase their imports. The strongest impact on international price levels can be expected for sugar where world prices could increase by up to 60% in 2014 compared to a situation with constant biofuel quantities at their current levels. Other prices would respond less dramatically, but could still gain some 4% in the case of cereals and up to 20% in the case of vegetable oils.

- Assuming unchanged policies, higher crude oil prices would further stimulate biofuels production. The degree to which biofuel quantities would increase strongly depends on parameters that are yet unobserved. Nevertheless, the results of this analysis suggest that the impacts of high oil prices on agricultural markets may well be dominated by their direct effects on agricultural production costs rather than by the increased demand for agricultural commodities.

Geography and time
- World wide, with distinction between OECD-countries and other countries
- Ten years.

7.4.3 FAPRI

Aim and focus
The Food and Agricultural Policy Research Institute (FAPRI) yearly present the world agricultural production, consumption and trade. In 2006 they present “The FAPRI 2006 US and World Agricultural Outlook” in which the new bio-energy policies in several large countries have been included in the 2006-baseline. Other major drivers of the 2006 baseline include the EU-sugar policy reform, the sanitary and phytosanitary shocks in livestock and poultry markets and the movements in the exchange rate.

Scenarios and results
FAPRI 2006 gives per (major) crop and dairy product (meat, beef, prof, broiler) an overview of supply, utilization, prices and trade. FAPRI works with assumptions on population, policy, exchange rates etc. In the FAPRI (2006) report one can find those assumptions on a detailed level.

Geography and time
- World-wide, distinguished by regions: US, EU, Japan, China, South-America.
- The time horizon is ten years.

The OECD-study “Agricultural Market impacts of future growth in the production of biofuels” mentions already the way biofuel production will be stimulated. While the OECD study focuses on higher oil-based fuel prices as a driving force, the FAPRI study determines ethanol and biodiesel prices by means of an inverse demand function.

Box 1: The Emergence of Biofuel Markets

The U.S. Ethanol Market

Following significant technical progress and major investments in new plants, U.S. ethanol production doubled between 2000 and 2004, with major consequences for both energy and agricultural markets. The Energy Policy Act of 2005 encourages further expansion of ethanol production by mandating the use of 7.5 billion gallons of renewable fuels by 2012. Higher fossil fuel prices also contribute to the expansion of the U.S. ethanol market. Ethanol prices at the plant typically exceed those of unleaded gasoline. The 51¢-per-gallon tax benefit for ethanol makes it price-competitive at the pump. Given Global Insight forecasts of petroleum product prices, both gasoline and ethanol prices are projected to decline slightly between 2006 and 2012. Gross margins for ethanol producers are at historic highs but are expected to decline as corn prices increase and ethanol prices fall. Increased production of ethanol translates into increased production of corn co-products for use as livestock feed. Most of the projected growth in ethanol production occurs in dry mill plants, where distillers' grains are the co-product. Estimated domestic feed use of corn co-products now exceeds that of wheat, sorghum, barley, and oats combined.

In summer 2005, FAPRI analyzed the impact of the implementation of the Energy Policy Act. Relative to the January 2005 FAPRI baseline outlook, the Act increased the estimated amount of corn used to produce ethanol over the 2010/11-2014/15 period by an annual average of 632 million bushels. Corn production increased while corn exports, feed consumption, and stocks declined. Corn prices increased by roughly 5% above baseline levels, with smaller price increases for other grains. In contrast, increased ethanol production resulted in more production and lower prices of corn by-products. These by-products displace both corn and soybean meal in livestock rations, contributing to a 10% reduction in soybean meal prices. Livestock and poultry sector effects were small in aggregate and depended on the composition of feed rations. The taxpayer cost of farm programs was reduced by $1.0 billion per year between 2011 and 2015. Increases in ethanol consumption could reduce tax revenue, given differences in the tax treatment of ethanol and regular gasoline. Net farm income exceeded baseline levels by nearly $300 million per year on average over the 2011-2015 period. Higher corn receipts were partially offset by lower government payments. (See the full report at http://www.fapri.missouri.edu/outreach/publications/2005/FAPRI_UMC_Report_10_05.pdf.)

In this year's outlook, ethanol production grows even more rapidly than estimated in the Energy Policy Act report. Projected U.S. production of ethanol alone exceeds the levels of renewable fuel use mandated by the Act, and expanded use of biodiesel and imported ethanol makes it even more likely that the targets will be exceeded. The pace of plant construction has been more rapid than anticipated earlier. The 2006 outlook assumes significantly higher prices for petroleum and gasoline than did the 2005 outlook, and these higher prices contribute to higher ethanol prices and increased profitability for ethanol producers.

World Biofuel Markets

Ethanol, the dominant biofuel in world markets, is gaining importance as an alternative fuel source as part of the renewable fuels initiative adopted by a number of countries. In addition to energy supply and environmental concerns, ethanol is gaining favor as an alternative use for feedstock. Currently, this ethanol push is policy driven, particularly through the U.S. Energy Policy Act, the Renewable Fuels Directive of the EU, and fuel mandates in Brazil. Brazil has led the way in using ethanol as an alternative fuel, drawing on its ability to produce ethanol inexpensively from sugarcane. The U.S. is the second-largest producer of ethanol after Brazil, followed by China and India.

The world ethanol price (the Brazilian price for anhydrous ethanol) increased by 26.2% in 2005, to $1.29 per gallon, reflecting increased demand for ethanol and high gasoline prices. The ethanol price is expected to decline in the coming years following the projected decline in gasoline prices. It begins to increase in 2010 as the demand for ethanol grows faster than production. By 2015, the world ethanol price increases by 1.8%, to $1.32 per gallon.

Brazil

Brazil has been using ethanol derived from sugarcane as fuel since 1903. In 1931, the Brazilian government mandated a 5% ethanol blend in gasoline. Prompted by the 1973 oil crisis, Brazil launched PROALCOOL, the National Alcohol Program, to encourage the use of fuel ethanol. Under this program, fuel ethanol production increased dramatically. In 1979, Brazil introduced

Figure 7.1a The Emergence of Biofuel Markets, Source: FAPRI (2006)

Overview: FAPRI 2006 Agricultural Outlook / 7

the large-scale production of alcohol-driven cars and light vehicles. Although the program lost ground during the late 1980s with the discovery of large oil deposits and the fall in international oil prices, the program regained its former vitality in recent years. Currently, Brazil mandates a 20%-25% ethanol blend in gasoline.

Production and consumption increased, respectively, to 4.8 and 4.2 billion gallons in 2005 and are projected to increase by 37.5% and 27.5% by 2015, as the dramatic rise in the use of flex-fuel cars boosts ethanol consumption in Brazil. Flex-fuel vehicles run on any mixture of hydrous alcohol, anhydrous alcohol, and gasoline. Sales of flex-fuel cars increased by 583% between 2003 and 2004, and the market share of flex-fuel vehicles rose from 20% in 2004 to 54% in 2005. Ethanol exports increase to 1.2 billion gallons by 2015, making Brazil the largest exporter of ethanol in the emerging world market.

Brazil has also started to focus on biodiesel development to reduce further its dependence on imported oils, which account for more than 80% of domestic petroleum consumption. In 2002, a new biodiesel fuel research program was initiated by the Brazilian government. In January 2005, the government mandated a 2% blend of biodiesel (B2) by 2008 and a B5 blend for all diesel sold in the nation by 2013 (Law 11.097/2005). In addition, financing and tax incentives for biodiesel production were offered in May 2005 (Law 11.116/2005). Brazil has diverse biodiesel production sources (soybean oil, sunflower oil, palm oil, and castor oil). Soybean oil, however, is believed to be the most competitive and efficient source for Brazilian biodiesel production. The future relative contribution of each type of oil to biodiesel production is uncertain. FAPRI projects a modest amount of soybean oil for biodiesel in 2008/09[1] (0.3 mmt) and increases the projection to 1 mmt at the end of the baseline period.

EU-15

Europe has a potential market for ethanol and biodiesel because of its targets for renewable fuels. According to the Renewable Fuels Directive of 2003, member states were to try to achieve a 2% share of renewables by the end of 2005 and a 5.75% share by the end of 2010. The directive will result in increased production of biodiesel and ethanol, but targets are unlikely to be achieved. The CAP reform of 2003 introduced a carbon credit of 45 euros per hectare to growers of energy crops, including biodiesel and bioethanol. Sugar beet became eligible for the carbon credit under the 2005 Common Market Organization sugar reforms.

The 2003 Renewable Fuels Directive increased ethanol production in the EU-15 to about 543 million gallons in 2005. EU-15 ethanol production is projected to continue its upward trend, reaching 831 million gallons in 2015, a 53% increase. EU-15 ethanol consumption increased by 40.7% in 2005, to 535 million gallons. Since consumption grows faster than production, the EU-15 becomes a net importer of ethanol, from net exports of 9 million gallons in 2005 to net imports of 121 million gallons by 2015.

The significant development of the EU biodiesel industry in the last 10 years makes the EU the global leader in biodiesel production. In the EU, the primary source of biodiesel is rapeseed oil. FAPRI takes into account the impact of the directive on rapeseed oil demand and projects that EU industrial use of rapeseed oil increases by 48% over the next decade, to 4.9 mmt in 2015/16. The EU became a net importer of rapeseed oil in 2005/06.

Japan

Japanese net imports of ethanol are expected to reach nearly 155 million gallons in 2006 and 258 million gallons in 2015. The main drivers of the growing support for the use of fuel ethanol in Japan are continuing growth in CO2 emissions, support of the Kyoto Protocol, and agricultural and energy policies. Japan permitted the use of 3% ethanol in gasoline in August 2003. With more widespread use of ethanol, Japan is likely to emerge as a major importer of fuel ethanol in the future.

China

China started to promote the use of ethanol-blended gasoline in 2000 and carried out experiments in some cities in 2002. Currently, nine provinces blend gasoline with 10% ethanol. China is now the world's third-largest ethanol producer, with the capacity to produce around 317 million gallons a year. At present, just over half that capacity is being utilized. China becomes a net importer of ethanol in 2009, and its net imports are expected to reach 72 million gallons in 2015.

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[1] Because of the structure of data sources, ethanol is reported in calendar years while biodiesel is reported in marketing years.

Figure 7.1b The Emergence of Biofuel Markets, Source: FAPRI (2006)

7.4.4 International Ethanol Model

Aim and focus

The International Ethanol Model specifies the ethanol production, use and trade between countries. The model incorporates linkages to the agriculture and energy markets, namely US crops, world sugar and gasoline markets.

Methodology

The international Ethanol Model is a non-spatial, multi-market world model linking ethanol to its input and output markets. It consists of the United States, Brazil, European Union(-15), China, Japan and a Rest-of-the-World aggregate to close the model.

The model consists of behavioural equations for production, consumption, ending stocks and net trade. Complete country models are established for the US, Brazil and the European Union(-15), while only net trade equations are set up for China, Japan and the Rest-of-the-World. The model solves for a representative world ethanol price by equating excess supply and excess demand across countries. Using price transmission equations, the domestic price of ethanol for each country is linked with the representative world price through exchange rates and other price policy wedges. Through linkages to the US crops and world sugar models, all the US crops prices are solved endogenously, including the US corn farm price and its by-products. Furthermore, the world raw sugar price is solved endogenously by equating excess supply to excess demand in the world sugar market.

Scenarios and results
This study analyses the impact of

- the gasoline price,
- the US corn price and
- the world sugar price on

on both ethanol and commodity markets.

Table 7.3 Impact of changes in gasoline price, US corn price and world sugar price on the ethanol and commodity markets, in USD per unit and in percentage (%)

	Ethanol price (USD/gallon)	**Gasoline price (USD/gallon)**	**Raw sugar price (USD/cwt)**	**Corn price (USD/bushel)**
Base line scenario	1.27	1.92	14.34	2.38
"20% gasoline price shock" (%)	1.25 (-1.91%)	2.30 (20.00%)	14.31 (-0.17%)	2.39 (0.59%)
"20% corn price shock" (%)	1.35 (6,57%)	1.92 (0.00%)	14.42 (0.55%)	2.86 (20.00%)
"20% world sugar price shock"(%)	1.35 (6.13%)	1.92 (0.00%)	17.21 (20.00%)	2.38 (0.19%)

Source: Tokgoz and Elobeid, 2006

Table 7.4 Impact of changes in gasoline price, US corn price and world sugar price on the production of ethanol in the US and Brazil, in million gallons

	United States	**Brazil**
Base line	7,064	6,165
Scenario "20% gasoline price shock" (%)	7,016 (-0.67%)	6,121 (-0.69%)
Scenario "20% corn price shock" (%)	6,811 (-3.67%)	6,315 (2.41%)
Scenario "20% world sugar price shock"(%)	7,132 (0.99%)	6,006 (-2.57%)

Source: Tokgoz and Elobeid, 2006

One can see that the increase in the gasoline prices affects the US and Brazilian ethanol markets differently because of the characteristic of their respective vehicle fleets.

An increase in the US corn price decreases the profit margin for ethanol plants. It leads to a reduction in ethanol production. Consequently, the US domestic ethanol price increases, making ethanol imports from Brazil relatively more attractive. The higher demand for ethanol import in the US increases the world ethanol price. Since Brazil is a low-cost producer of ethanol, it captures most of the increase in the US imports despite the high import tariffs.

The increase in the world price of raw sugar diverts more sugarcane into the production of sugar relative to ethanol in Brazil. This results in lower production of ethanol and lower net exports from Brazil. The lower supply of ethanol in the world market leads to an increase in the world ethanol price. The results of the scenarios show that ethanol and sugar prices tend to move together in Brazil.

7.4.5 SCENAR2020

Aim and focus
The objective of the study is *to identify major future trends and driving factors and perspectives and challenges resulting from them for European agriculture and rural regions until the year 2020.* The focus of the study will be an analysis of key driving forces and the provision of a well developed reference scenario under the assumption of continued CAP reform (…) and taking into account the framework discussions in the Doha Development Round. The study will also

examine alternative relevant and consistent scenarios. The result of the Scenar2020 study is the identification of future trends and driving forces that will be the framework for the European agricultural and rural economy[5] on the horizon of 2020.

Scenar2020 provides a systematic review of the primary variables that rural and agricultural policies have to take into account. These are (a) the rural demographic patterns, (b) the agricultural technology, (c) the agricultural markets, and (d) the natural and social constraints on land use that are likely to exist in 2020. Social and economic factors, both conditioned by technology, have a bearing on these primary variables, and these factors are both endogenous and exogenous. Technology determines what is possible in every domain, and social (consumer) demand determines what is economically viable. Social demand – as it affects the agricultural sector – does not only reflect consumer preferences in terms of food, but also environmental and health concerns, including the commitment by society as a whole to the wise use of natural resources (water, soil) and biodiversity preservation. It is these environmental and health concerns that define the natural and social constraints on land use. World markets and local production costs – including compensation measures that may offset operating charges – will inevitably both determine what is economically feasible in the EU and direct agricultural production to the geographical locations worldwide that provide sustainable livelihoods for farmers, or the greatest return on investment for agro-industrial enterprises.

In the Scenar2020 study first results of an analysis of the EU biofuel directive have been presented.

Methodology
The method used is to build a reference scenario (‘baseline’) that is based on an analysis of trends from 1990 to 2005, which is projected forward to 2020; the trend analysis provides a substantiated basis for determining the long-term driving forces that are reflected in the reference scenario. It is assumed that economic, agricultural and environmental policy may cause an inflection in these trends, so these are studied as a second level set of driving forces, also to be taken into account in the scenario exercise. The relative importance between various long-term driving forces and policies is understood by comparing two alternative – or ‘counterfactual’ – scenarios (‘liberalisation’ and ‘regionalisation’) to the reference scenario.

The comparison between scenarios occurs in two steps: the first is a modelling exercise that analyses the likely outcome of each scenario using simulation models and other quantitative analyses. Where appropriate and necessary, these in-depth scenario analyses are complemented by qualitative analyses and expert judgement. The result is a description about how each scenario is expressed in spatial terms, across the EU-25, and in some case extended to the candidate countries for accession. The second step is a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, which is applied to each scenario in order to understand the implications in the following domains: demographic developments, dynamics of rural economies, and the future of the agricultural economy (specifically in terms of farm structures, production systems, and farm population demography). This occurs through the definition of ‘typical’ regions; such ‘typical’ regions are characterised by similar responses to the simulated factors. (See Enclosure 1)

Results
The results of Scenar2020 indicate that crop production for biofuel purposes (including cereals, sugar and oilseeds) will increase in the coming 15 years in the EU even without the implementation of the mandatory blending obligation imposed by the EU biofuel directive (Baseline scenario in figure 7.2). Under the baseline scenario crop production expands in all regions of the EU and contributes 3.6 percent of total fuel consumption for transportation. Different level of support to farmers does not alter the outcomes significantly, such as high support under the Regionalization scenario vs. low support under the Liberalization scenario.

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[5] The difference between agricultural and rural economy is made explicit. It has become increasingly apparent that agriculture in many rural regions is not the principal economic driver.

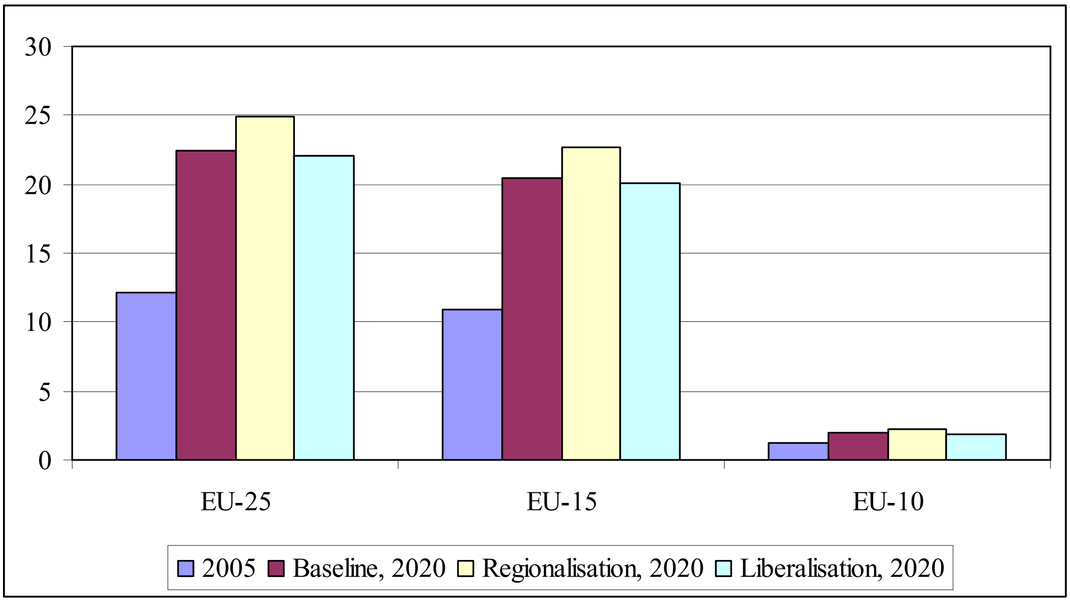

Figure 7.2 Production of crops for energy under different scenarios in the EU, 2005 and 2020, in million tons. Source: Nowicki et al., 2006.

The major uncertainty with regard to all conclusions concerning the future of biofuels is the tightness of oil/energy markets. Therefore any scenario result depends on the assumption made on future development of crude oil price. For this study an increase of crude oil price by 1.5% p.a. has been assumed. Therefore, the impact of biofuels on European agriculture may be under-estimated: 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, if all feedstocks for biofuel production are grown domestically. Table 7.4 shows the required area of biofuel crops (first generation) when the biofuel directive is implemented.

Table 7.4 Area and production of biofuel (crops) under Biofuel directive, in million ton

	2005	**2010**	**2020**
EU-25			
Biofuel crops			
Production	12.12	27.66	39.89
Area (Mha)	3.65	6.98	8.62
Biofuels			
Domestically produced	3.79	8.74	12.60
(Net)imported	0.81	6.30	8.40
EU-15			
Biofuel crops			
Production	10.91	25.06	36.33
Area (Mha)	3.25	6.23	7.72
Biofuels			
Domestically produced	3.42	7.92	11.49
(Net)imported	1.02	5.76	7.49

Source: Nowicki et al., 2006

The Scenar2020 study shows, that the 5.75% objective for 2010 in itself will require 15.03 million tonnes 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 (a) 8.74 million tonnes of biofuels, (b) 58% of total biofuels used and (c) 5.5% of total agricultural land demand.

A corollary of the increased demand for biofuels is the increased resort to biobased materials (partially motivated to replace plastics, a petroleum derivative); the conjunction between the demand for biofuels and the demand for biobased materials is likely to create competition with other demands for agricultural commodities.

The demand for biofuels derived from agricultural commodities could be rapidly offset by biomass, using second-generation bio-energy production technology, as a substitution feedstock for the bio-ethanol fraction that would be fully operational on an industrial scale as early as 2015. The second generation of biofuels is currently considered to be more beneficial because the reduction of greenhouse gas emissions is larger and it is (perhaps) less land intensive.

The Scenar2020 study clearly shows how non-food demand of agricultural products (e.g. energy) competes with food demand. This implies that first, increasing food prices with possible adverse effects on food importing (developing) countries; and second, a land expansion with implications for the environment. A trade-off between lower greenhouse gas emissions and adverse effects of this expansion and intensification in terms of for example biodiversity.

7.4.6 EU-RURALIS

Aim and focus
The aim of EU-RURALIS is to support the strategic policy discussions concerning the future of European rural areas (the EU-27). EU-RURALIS makes it possible to analyse the impacts of policy options in the longer term – up to 2030. By way of support for these discussions it is necessary to identify autonomous and policy-induced developments in the form of various scenarios. The long-term results in respect of a number of people-planet-profit indicators can be translated back to the shorter term, i.e. the policy challenges in the coming years.

Methodology
EU-RURALIS is an attempt to bring existing knowledge and experience together rather than inventing all possible research modules themselves. This applies to the choice of scenarios (see later) and to the use of data and models (authorised data, tested models). In figure 7.3 the general framework of the present study is visualised.

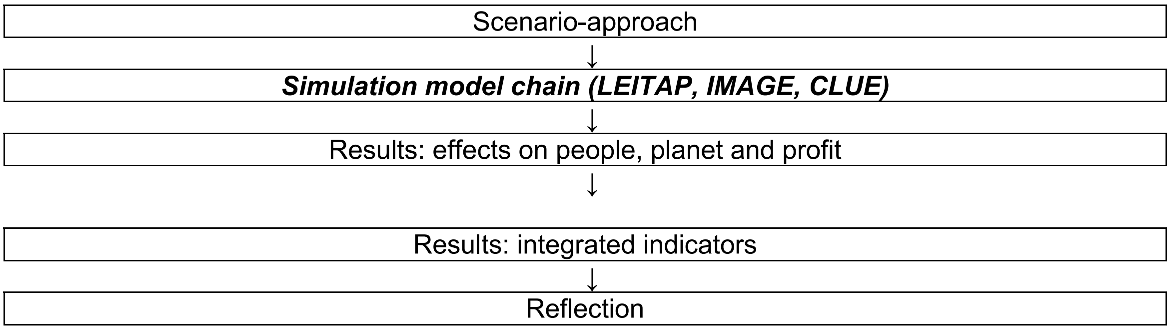

Figure 7.3 General framework for EU-RURALIS project

The simulation model chain (LEITAP, IMAGE and CLUE are “outside the EU-RURALIS application”. We will shortly discuss them and focus on LEITAP, while this model tries to say something about economics.

But first of all we will discuss some central concepts of philosophies of EU-RURALIS. The DPSIR-model is essential within EU-RURALIS. *Driving Forces* (D) – either direct or proximate or indirect or distance) affecting a defined system by so-called *Pressures* (P) affecting its *state* (S). This can be seen as an *impact* (I), which has to be assessed from society’s interests in terms of people, planet and profit. This assessment can lead to policy interventions – *responses* (R). Concerning the driving forces, EU-RURALIS distinguishes a number of forces acting both in the past and the future:

- Demography: growth/ decrease of population, migration and significant change in age distribution.
- Global change: expected range of climate change, change in sea-level according to IPCC scenario studies.
- Political administrative regime: depending on the level of European coordination, legislation and regulations, CAP-measures.
- Macro-economy/trade: to be considered as a major driving force, rooted in changes in production and consumption relationships, import and export of goods and services and growth or decline of certain sectors.
- Progress in technology and diffusion of technological findings.
- Changes in values in society, consumer concerns and behaviour.

Furthermore, the EU-RURALIS works with a scenario-approach and the (3P) sustainability-approach of people-planet and profit.

LEITAP is an adapted version of the general equilibrium model of the Global Trade Analysis Project (GTAP). GTAP is initiated with the goal of supporting high-level quantitative analysis of international trade, resource and environmental issues in an economy wide context. The GTAP project is supported by international agencies, e.g. WTO, World Bank, OECD, UNCTAD. The GTAP project develops and maintains a database, a multi-region multi-sector general equilibrium model. GTAP is characterized by an input-output structure that explicitly links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing to the final assembling of goods and services for consumption. GTAP covers all world trade and production and includes intermediate linkages between sectors. For the purpose of EU-RURALIS a special version of GTAP database and model has been designed. The adaptation makes it more appropriate for the analyses of the agricultural sector.

The extensions to the standard GTAP model concern:
- Land allocation6
- Variability of total area
- Yield and feed conversion
- Feed conversion in livestock
- Feed demand in food processing industry
- Segmentation of factor markets and endogenous production quota
- Agricultural production quota

It is suggested to read Klijn et al. (2005) to find more details.

Scenarios and results
The four scenarios of EU-RURALIS 1.0 were based on the general scenario storylines from the International Panel on Climate Change (IPCC) but these were made more specific for the subject of EU-RURALIS 1.0. Moreover, a number of quantitative assumptions were taken from the CPB-report “Four futures for Europe”. In figure 7.4 the scenarios are presented.

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[6] EU-RURALIS does not take the forestry land into consideration; the focus is on agricultural land use.

Global economy Market-based solutions are most efficient to achieve strong economic growth and optimise demand and supply of goods, services and environmental quality	**Global**	*Global co-operation* Market-based solutions to exploit comparative advantages, but strong internationally co-ordinated efforts are needed to address wealth distribution, social justice and the environment.
Low regulation		**High regulation**
Continental markets Market-based solutions among like-minded countries, but shielded from countries with different values and standards. Cultural identity, strongly anchored in the countryside, must be preserved.	**Regional**	*Regional communities* Self-reliance, environmental stewardship and equity are the keys to sustainable development. Local communities are the cornerstones of society.

Figure 7.4 Scenarios in EU-RURALIS

An important goal of EU-RURALIS is to be able to explore the impacts of different policy measures. The base situation is the 2003 Common Agricultural Policy (CAP) – with the import tariffs, domestic support and sugar and milk quota (EU-25). Policy makers have prioritized the Common Agricultural Policy, the biofuels and policy on Less Favoured Area Option. Concerning the biofuel-policy policy makers are aware of the huge consequences on the land use of Europe.

Under the EU-RURALIS project explorative scenarios analyse the pathways and outcome of conceivable futures. Explicitly these scenario- approaches try to grasp possible and contrasting futures instead of attempting to analyse the impact of a single change in a policy measure.
For the Common Agricultural Policy (CAP) of the European Union the following policy option are analysed under EU-RURALIS.

1. Shift from market price support to income support. This trend implies that support becomes less trade distorting and fulfils better the objective of income support.
2. Reduction of the level of support.

Partly due to pressure from GATT/WTO, the EU agricultural policy has undergone major reforms in recent years, and this process is set to continue. Currently, there is the matter of the reduction in the guaranteed prices for grain, beef, dairy and also sugar, see following table.

The relationship between current EU prices and world market prices varies greatly per product. For grain, the EU is already competing at more or less the same level. Generally speaking, this means that exports without refunds appear possible. For beef, the current internal EU prices are higher than the world market price. A direct comparison is difficult in view of the differences in quality. Incidentally, the EU's self-sufficiency for beef has fallen below 100%, due to the decline in the number of dairy cattle (due to milk quotas). The abolition (decoupling) of the beef premiums could result in a further reduction in production. The internal butter price is currently still too high for exports without refunds to be possible; the difference is smaller for skimmed milk powder. For sugar, the proposed price reduction by no means ensures a bridging of the difference with the world market. Account must be taken of the interests of imports from developing countries (EBA, ACP) and the Balkan region, as well as the isoglucose scheme (a grain-based sugar substitute).

Table 7.5 EU decisions and world market prices.

Product	MacSharry price reduction (1993-1996)	Agenda 2000 price reduction (2000-2002)	Mid Term Review price reduction (2004-2007)	EU price 2004 (€ per tonne)	World market price (€ per tonne)
Wheat	30%	15%	0	100	100 d)
Beef	15%	20%	0	1,560 b)	1,500- 2,000 e)
Butter	0	0	25%	2,464 as at 1/7/2007 c)	1,400 d)
Skimmed milk powder			15%	1,747 as at 1/7/2006 c)	1,700 d)
Sugar	0	0	33% a)	632; 421 in 2007/2008	250 f)

Proposal dated July 2004 led to a reduction in the current intervention price from €632 to €421 per tonne of white sugar in 2007/2008; the market price in the EU is still over €700;
Intervention price; basic price in the EU regulations is €2,224; the European market price in 2004 was approx. €2,800 per tonne of carcass;
Intervention price set by decisions taken in 2003;
Expectations of the European CIE and OECD are given in dollars; in € depending on the exchange rate (currently approximately €/$: 1.3/1);
FAO; Annual Averages, Beef (Australian, cow beef, boneless, cif, USA) Year 2003 US$/tonne 2,110;
The average export price of white EU sugar is €223 per tonne in 2002/03 and €280 in 2001/02.

The above indicates that the EU has not yet achieved the ultimate objective of full liberalisation for all products through modifying the prices. Schemes restricting production (dairy, sugar, etc.) will continue to be necessary until this is achieved.

Income supplements will be awarded in order to compensate for the reduction in the guaranteed prices. Up until the Mid Term Review decisions (2003), these were linked with the quantity of crops grown and the number of animals kept. Due to this link, they did in fact form a type of premium on production. Partly due to pressure from the WTO, these premiums were therefore ‘decoupled,’ though not fully for some products (starch, meat, etc.). The supplements will make up a large share of the income of many cattle farms and arable farms - generally more than half - and are therefore significant for the continuity of these holdings. The last EU CAP reforms were mainly along the lines of the first trend mentioned above. Market support is replaced by income support, although the second trend is also present because farmers are not fully compensated. Due to WTO pressure this trend is also visible in other regions.

With regard to the policy options the EU-RURALIS scenarios include the following options:
(1) Reduction of market price support [market price support is fully or partially reduced or is kept constant. Therefore, depending on the scenario EU internal prices get closer to world prices]
(2) Change in income support [farmers face an elimination, substantial reduction, constant or even increasing level of decoupled income support].
(3) Biofuels Directive [5.75% or 11.5% of fuel used for transport purposes have to stem from bio-based material].

All options below are therefore combined with a third option (without a mandatory blending, with a blending obligation of 5.75% or 11.5%). The reform on market price and income support are assumed to take place multilateral and economy-wide. The blending obligation is only implemented for the EU25. The effects of these options will be run through the model chain and result in figures for the impact indicators.

Table 7.6 Plausible combined options for agricultural policy scenarios

			Market Price Support			
			Constant price support		**Decreasing price support**	**Liberalisation**
			G3		G2	G1
Income Support	**Increasing support**	C4	B2		A2 B2	
	Stable support	C3	A2	B2	A2 B1 B2	B1
	Decreasing support	C2	A2	B2	B1	A1 B1
	No support	C1	A2			A1

a) Areas in green describe the start position policy button.

To illustrate the enhanced use of biofuels as the consequence of the EU biofuels directive the first graph (fig 7.5) illustrates the initial shares of biofuels in transport use in 2005.

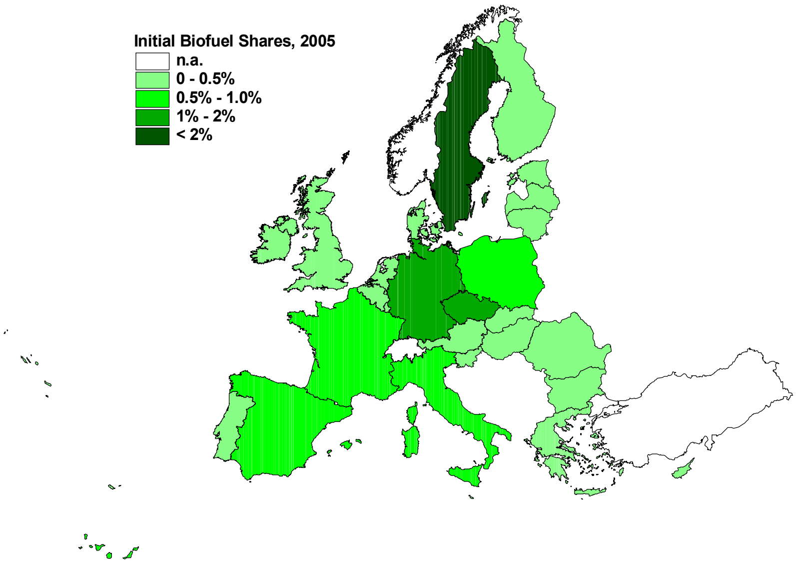

Figure 7.5 Initial Share of Biofuels in Transportation in the EU25, 2005

Sweden together with Germany and the Czech Republic are those countries with the highest share in the use of biofuels in transportation. Under a scenario which assumes no mandatory blending the use of biofuels in transportation will increase endogenously due to changes in relative prices (prices of bio-based crops versus crude oil), see figure 7.6. It becomes clear that even without a mandatory blending the share of biofuels use in transportation increases significantly.

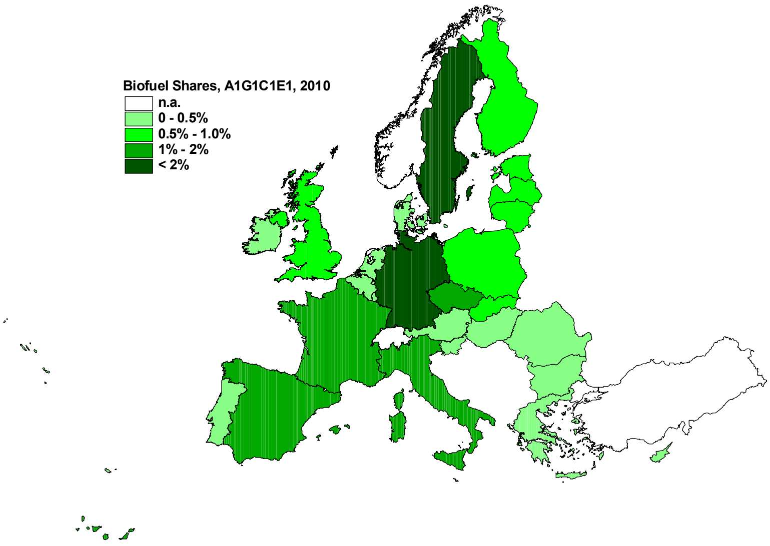

Figure 7.6 Share of Biofuels in Transportation in the EU25, 2010 – No mandatory blending

To understand the impact of a mandatory blending in the use of bio-based crops in fuel production, the following two graphs illustrate the change in the land use for arable crops in a scenario where income and price support are stepwise eliminated. Figure 7.7 illustrates the impact of the envisaged 5.75% blending obligation and figure 7.8 presents the change in arable land use for a scenario which assumes a blending obligation of 11.5%.

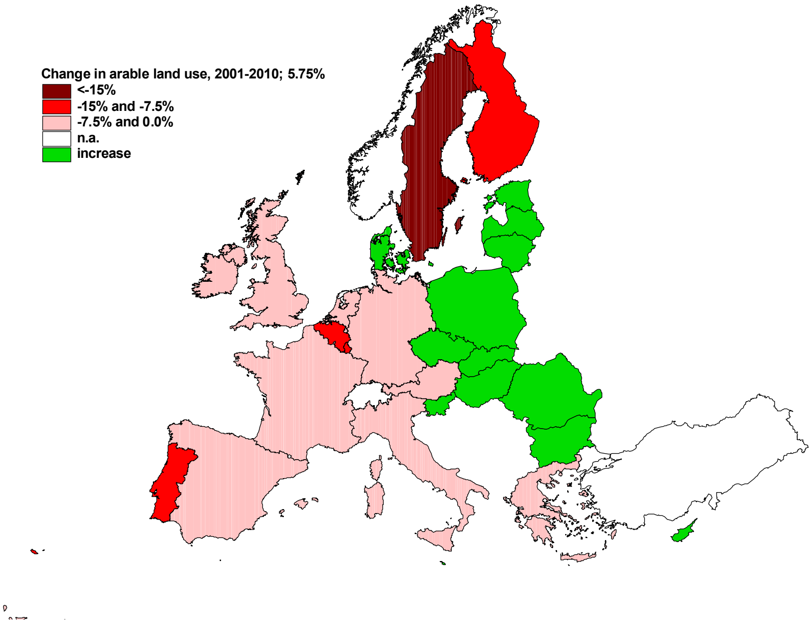

Figure 7.7 Change in Arable Land us in the EU25, 2001-2010 – Mandatory blending: 5.75%

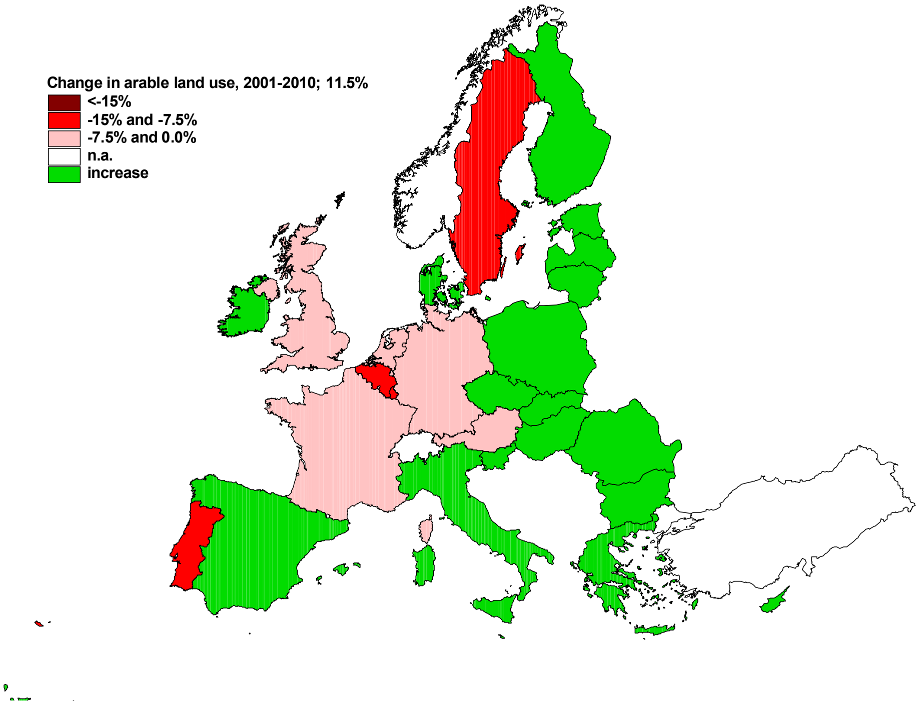

Figure 7.8 Change in Arable Land us in the EU25, 2001-2010 – Mandatory blending: 11.5%

Figure 7.9 shows the effect of the biofuel directive on production and price. The baseline (no biofuel directive) = 100.

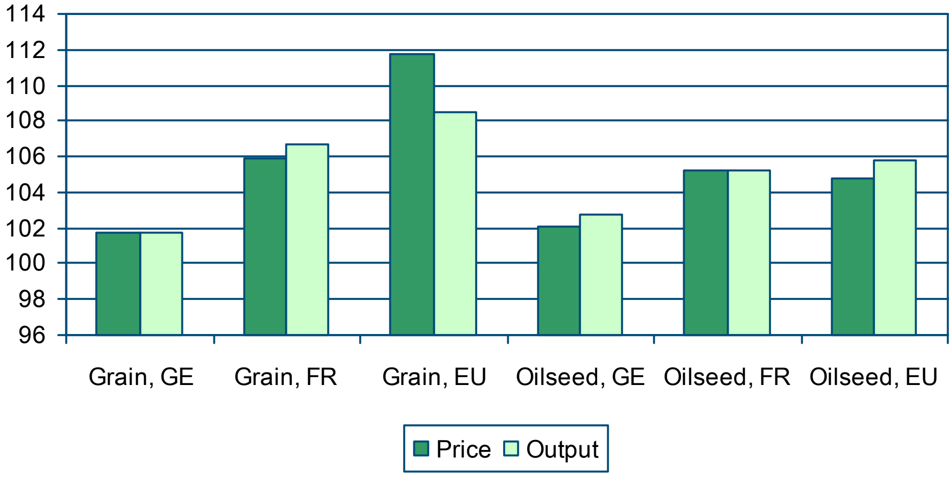

Figure 7.9 The impact of biofuel directive on production and price (Source: Banse and Grethe, 2006)

It is clear the EU biofuel policy is likely to have a significant impact on agricultural prices. Biofuel polices may heavily affect the price level for agricultural products.

Geography and time

- EU-RURALIS sets the time horizon quite far (year 2030) but also tries to include shorter term steps (e.g. per 10 years).
- EU-RURALIS is focused on the EU and covers all EU-countries. It aims to downscale the results in order to say something on regional level.

7.5 Resulting data for key parameters

As we can see from the previous paragraphs economic models often try to understand what happens under different conditions. Most of the models work with scenario's in which policy, oil prices or other external factors differ. These developments in driving forces are decisive. But: which driving forces are the most important? And: what influence do they have? The study Scenar2020[7] aims to give answers on these questions. Scenar2020 aims at identifying of future trends and driving forces that will be the framework for the European agricultural and rural economy on the horizon of 2020. The study provides a systematic review of primary variables that rural and agricultural policies have to take into account, such as rural demographic patterns, agricultural technology, agricultural markets, and the natural and social constraints on land use that are likely to exist in 2020. As written in chapter 3 the method used is to build a reference scenario ('baseline') that is based on an analysis of past trends projected forward to 2020. The relative importance between various policy frameworks is understood by comparing two scenarios ('liberalization' and 'regionalization') to the reference scenario. While the baseline scenario establishes a possible and reasonable perspective of what might happen until 2020 from today's perspective, this scenario is contrasted by two alternative scenarios representing two possible but extreme policy choices. The regionalization scenario assumes that the WTO negotiations would not conclude and bilateral trade agreements would become more important. Under the liberalization scenario a complete withdrawal of price and income support to farmers. It should be mentioned that the EU biofuel directive is only implemented in the regionalization scenario.

The major drivers which have impact on “Europe 2020” and within that context the availability of biomass are the following:

- Population growth pattern
- Macro-economic pattern
- Consumer preferences
- Agri-technology and
- Environmental conditions.

Other drivers are: policy (agricultural policy, structural policy, environmental policy, WTO and other international commitments). In the paper “LEITAP: Illustration of Underlying Assumption of the Baseline Scenario until 2020“ (see Appendix 12) the global implications of the three scenarios on the main drivers have been assessed.

7.6 Conclusions

- It is critical to understand the dynamics of the relationship between biofuel and agricultural markets. The studies illustrate that the role of biofuel need to take into consideration world agricultural markets. The price of corn and oilseed is impacted by and impacts not only biofuel production, but also the prices of other crops – worldwide. The impact also extends to the livestock sector through feed prices. A model which takes those effects on prices into account is necessary. An ideal model is able to illustrate the effects of competing claims of fuel, feed and food.
- EU-RURALIS is focused on the EU-situation and assesses the biofuel policy. At this moment (January 2007) the final results are not available yet. Therefore, it is too early to say something about the impact of biofuels on food and feed. However, one sees the influence of the biofuel policy on prices of food and feed already. Prices of grain and oilseed are increasing in Europe and other parts of the world.
- The economic studies that 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.
- An economic assessment requires dealing with supply and demand of food, feed and fuel. Supply and demand have to be fed by all relevant driving forces. A higher demand of bio fuels has consequences for prices for food and feed. These consequences will lead to a new

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[7] SCENAR 2020 is a answer to Tender AGRI/2005/G4/02 from the European Union.

equilibrium for biomass commodities. Consequently, not only the assumptions concerning driving forces have to be assessed; the most decisive question is whether the principle of finding a new market equilibrium with new prices has been part of the study.

- The driving forces behind agro-production are: demography, global change (environment), political and administrative regime, macro-economics, agritechnology and the 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. There is the most actual input for the driving forces, determining supply and demand.
- The driving forces show a dynamic; they are not static. Therefore, almost all economic studies assess the consequences of different scenarios. Economic studies do not provide a prognosis, but they try to show the possible effects of changing policy. Therefore they always work with the principle “what …. If….”
- Driving forces and scenarios form the focus of the EU-project SCENAR 2020.

7.7 References agricultural economics

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Appendix 1 Fact sheets of biomass potential studies

Table A1.1 Biomass potential studies included in the review

Study	Authors	Title	Bibliography
1 Fischer	G. Fischer, S. Prieler, H. van Velthuizen	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, 2005.
2 Hoogwijk A	M. Hoogwijk, A. Faaij, B. Eickhout, B. de Vries, W. Turkenburg	Potential of biomass energy out to 21000, for four IPCC SRES land-use scenarios	Biomass and Bioenergy 29 (2005) 225-257
3 Hoogwijk B	M.Hoogwijk, A. Faaij, B. de Vries, W. Turkenburg	Potential of biomass energy under four land-use scenarios. Part B: Exploration of regional and global cost-supply curves	In: M. Hoogwijk, On the global and regional potential of renewable energy sources, PhD Thesis, Utrecht University, 2004.
4 Obersteiner (Afforest)	M. Obersteiner, G. Alexandrow, P.C. Benitez, I. McCallum, F. Kraxner, K. Riahi, D. Rokityanskiy, Y. Yamagata	Global supply of biomass for energy and carbon sequestration from afforestation/reforestation activities	Mitigation and Adptation Strategies for Global Change 11(5-6) 1003-1021, 2006
5 Perlack (USDA Billion-Ton)	R.D. Perlack, L.L Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, D.C. Erbach	Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply	USDA/DOE report DOE/GO-102005-2135, 2005
6 Rokityanski (Afforest)	D. Rokityanskiy, P. Benitez, F. Kraxner, I. McCallum, M. Obersteiner, E. Rametsteiner, Y. Yamagata	Geographically explicit global modeling of land-use change, carbon sequestration and biomass supply	Technological Forecasting and Social Change, 74(7), 1057-1082.
7 Smeets (Quickscan)	E.M.W. Smeets, A.P.C. Faaij, I.M. Lewandowski, W.C. Turkenburg	A bottum-up assessment and review of global bio-energy potentials to 2050	Progress in Energy and Combustion Science, 33(1), 56-106.
8 Wolf	J. Wolf, P.S. Bindraban, J.C. Luijten, L.M. Vleeshouwers	Exploratory study on the land area required for global food supply and the potential global production of bioenergy	Agricultural systems 76, 841-861, 2003.

Table A1.2 Scope and results of the biomass potential studies

No.	Types of biomass	Time horizon	Regional scope	Potentials	Methods
1	Energy crops: miscanthus, willow, poplar	Not specified (current potentials)	Eastern Europe, Northern and Central Asia	FSU and Mongolia: 3.5 EJyr and Eastern Europe 2 EJ/yr	Assessment of eco-physiological biomass yields; excluding forestry land and land very suitable for cereals
2	Energy crops	1996-2100 scenario analysis	Global, (abandoned, low-productivity and rest land)	in 2050: 322-657; in 2100: 395-1115	Use of integrated assessment model IMAGE 2.2. Assessment of food and material demands and modeling of energy crops on grid cell level
3	Energy crops	2000-2050 scenario analysis	Global	in 2050: 130-270 EJ/year below 2 Euro/GJ	Top-down estimation of biomass cost supply curves using regional biomass potentials from Hoogwijk et al., 2005
4	Biomass from afforestation/reforestation activities, includes short rotation forestry	2000-2100	Global	In 2100: 1200-1600 EJ below 2 Euro/GJ (cumulative from 2000-2100)	Demand driven analysis of bioenergy potentials and sink enhancement, evaluation of net present values (NPV) of forest production (including payments for carbon sequestration) compared to agricultural production
5	Residues from forestry, argiculture, processing industry and waste; fuel treatment thinnings, perennial grasses and woody crops	2030	USA	Forest resources 368 Mt (ca. 6 EJ), from crops 194 -998 Mt (ca. 3-16 EJ)	Bottom-up analysis of resources in forestry and cropland based on outlook studies from agriculture and forestry
6	Forests resources andr woody energy crops	Up to 2100	Global	In 2100: 175-230 EJ/yr	Demand-driven analysis of land use change mitigation options on grid-cell level; methods similar to Obersteiner (NPV comparison)
7	Energy crops, forest resources, agricultural and forestry residues and waste	2050	Global	367-1548 EJ	Bottom-up modelling of potentials and review of existing potential studies
8	Energy crops	2050	Global	in 2050: 0-51 Gt (ca. 0-800 EJ/yr)	Bottom-up assessment of food supply and remaining potentials for bioenergy

Table A1.3 Yields of energy crops and forestry in the biomass potential studies

No.	Methods	inputs production	water	type of land	technology	type of crop	demand/ supply	resolution
1	FAO/IIASA Agro-Ecological Zones Approach (AEZ) expanded with model to assess tree species. Models are based on eco-physiological models of Kassam and on Chapman-Richard biomass increment model	not specified	rainfed soil moisture influences biomass yields; model uses crop-stage-specific and total growing period reduction factors	suitable land, excluding forest land, other land and land highly suitable for cereals; soil data for North and Central Asia from FAO and soil map Europe; land cover from IIASA/LUC and CORINE;	potential yields are reduced by a factor taking into account pests, diseases and weeds	miscanthus, willow and poplar	demand not taken into account; supply-driven study	GIS-grid cell (5 km for Asia and 1 km for Europe)
2	theoretical potential from net primary production assuming (NPP); geographical potential for land not used for food production	indirectly included in management factor (MF)	assuming optimal water use efficiency in rainfed yield, irrigation implicitly included in MF	agricultural land not used for food (surplus cropland or decreased suitability soil), low-productive area, rest land (excluding forests, bioreserves, tundra)	MF representing management and technology (maximum MF is 1.1-1.5 in scenarios); learning assumed with annual growth rates of crop yields (1.6% or 1.2%)	woody energy crops in short rotation - not specified	energy crops production isnot demand-driven; supply-driven study	grid cell (0.5 degree)
3	Same scope for geographical potential as Hoogwijk A, costs are based on labour, capital and land costs	-	-	-	Cost reduction due to learning curves related to output in a region; capital costs depend on region but not on management	-	-	-
4	Net primary production (modelled from gross primary production by Alexandrov et al. 1999); timber production from allometric relationships	not specified	rain-fed production included in NPP	Land cover: IGBP => used are closed shrublands, open shrublands, croplands, grasslands, savannas; exclusion of h land with agricultural suitability above 50%	modest growth assumption; less intensively managed plantation species; no learning; silvicultural production costs based on harvesting and trucking	Natural vegetation, energy plantation not specified	Demand for afforestation/ reforestation projects modelled by comparing NPV of land use (incl. carbon prices) to agricultural NPV	grid-cell (0.5 degree)
5	Yields from USDA Forestry Inventory and Analysis and USDA Agricultural Outlook; Future yield increases analysed: increase in corn yields between 25-50% assumed, similar changes for wheat and soy bean (data on crop yields from USDA Baseline projections)	different technology levels assumed, inputs not further specified	not specified (related to agricultural statistics)	forestland (timberland with high yields and other forest land), pastures on cropland (permanent pastures are excluded), cropland and set-aside cropland	technology changes investigated in scenario analysis: yield increases, more efficient harvest technology, more no-till agriculture, changes in residues-to-grain ratio of soybeens; removal of up to 60-75% residues; accessibility of forest residues limited	Forestry residues and non-merchantable biomass from forest ; residues of grains (corn, wheat, soy-beans) and oilseeds; switchgrass, hybrid poplars, woody crops for fibre production (only 25% available for biomass)	Supply is limited by accessibility of forests and residues, economic consideration indirectly included; supply-driven study	not specified

Continued Table A1.3

No.	Methods	inputs production	water	type of land	technology	type of crop	demand/ supply	resolution
6	Use of global vegetation model (TsuBiMo, Alexandrov 2002) based on net primary productivity	not specified	rainfed production included in NPP	Excluded are areas for food production and urbanisation, 80% of remaining areas available for afforesta-tion projects; land-cover database from IGBP (conservative dataset with respect to standing biomass)	see Obersteiner et al.	see Ober-steiner et al.	see Ober-steiner et al.	see Obersteiner et al.
7	Crop yield data from IMAGE based on crop growth model (woody energy crops)	Different levels of inputs and technology assumed	Scenario analysis of rain-fed and irrigated yields	Surplus area of agricultural land (i.e.cropland and pasture) for energy crop production; surplus forest growth based on woodfuel and industrial roundwood demands; excluding protected and inaccessible forest areas.	Very high to super high levels of crop production technology influencing also harvest indices; super high level of woody energy crop pro-duction (i.e. MF of 1.5 A1 scenario); global average yield: 16- 21 t/ha for bioenergy crops; wood from forest plantation from FAO projections (three scenarios)	Conventional crops (e.g. sugar cane, wheat, maize), woody bioenergy crops and grasses (e.g. miscanthus); trees outside forests, forest plantations and natural growth	Food and wood demands determine the amount of residues and waste using re residues-to-product-ratios and recoverability fractions, energy crop production is not demand-driven	regional
8	Analysis of biomass potentials on surplus land with crop growth model	High and low level input system defined	irrigation indirectly included in high-level input system	Surplus agricultural land, i.e. agricultural land and potentially suitable area for agricultural production	High level input system - external inputs maximised for crop yields; low level input system with best technological and ecological means (no chemical fertilisers and biocides)	Assuming biomass production to be equivalent to global rainfed grass production (4-7.3 t/ha in the high-input/low-input system).	Energy crop production not demand driven; supply-driven study	grid-cell (1 degree)

Table A1.4 Food demand and supply in the biomass potential studies

No.	Methods	diet	inputs production	water	type of land	technology	resolution	type of crop	demand/supply
1	Food is not modelled, but land highly suitable for cereals (for at least one of seven cereals) is excluded								
2	Food production based on AEZ approach of FAO in Agricultural Economy model of IMAGE; feedback of climate changes on yields	Food intake on a daily per capita basis divided into basic and affluent products, related to regional incomes; food demands modeled for regions and influenced by social/environmental scenario priority	indirectly included in MF	Mainly rainfed production; irrigation is indirectly included in MF	agricultural land; production modeled using a soil quality factor representing: 1) nutrient retention and availability, 2) level of salinity, alkalinity and toxicity, 3) rooting conditions	regional MF assumed in IMAGE (averages for scenarios are: 0.78-0.82 in 2050 and 0.86-0.89 in 2100), learning over time is assumed (average maximum MF is 1.3)	grid cell (0.5 degree)	12 food crops, type of fodder influenced by GDP assumption	food demand divided into basic and affluent products; no detailed modeling of fodder (and wood) demand such as residues could be estimated, regular demand for food and forestry products assumed to determine available land for energy crops
3	Same scope for food production as Hoogwijk A								
4	Agricultural production is compared to afforestation/reforestation via NPV	not applicable	agricultural production NPV modeled top-down from land suitability and population density, regional land prices	not specified	land suitability for agriculture determined from soil and ecosystem property, dataset from Ramankutty et al. 2001(www.sage.wisc.edu/atlas)	not specified	grid-cell (0.5 degree)	Trees/short rotation crops are not specificed	Only forest sector consumption regarded. Demand modelled from socio-economic drivers, remaining woody biomass can be used for bioenergy
5	Food production data from USDA Agricultural Outlook	Current food demand directly translated with population increase; increased demand of wood products assumed	different technology levels assumed, inputs not further specified	not specified (related to agricultural statistics)	agricultural land	Assumption on technology as for crop yields (residues are used for bioenergy)	USA	grains and oilseeds for food and feed productions	Wood demand is driver for forest harvesting leading to primary and secondary residues; food demand and export requirements deducted from grain nproduction and oilseeds available for bioenergy; food demand for domestic use and for exports considered (USDA projections)
6	Area limitation to assure for food security (in %) from agricultural assessment (Tubiello and Fischer, 2006)	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable

Continued Table A1.4

No.	Methods	diet	inputs production	water	type of land	technology	resolution	type of crop	demand/supply
7	Crop growth modeling results from IIASA based on AEZ.Climate change not included in crop modeling	Per capita food intake in: into vegetal products, animal products and marine food; global average in 2050: 3302 kcal/cap*day; projections from FAO	Two levels of crop production: very high - super high; three levels of technology for animal production (differ with regard to e.g. breeding, feed supplement); three animal production systems: pastoral, landless, mixed system.	Scenario analysis of rain-fed and irrigated yields	Crop production allocated to land using agricultural suitability; forests, permantent pastures, build-up land and permanent crops are excluded; other land (e.g. wastelands, uncultivated land) assumed to be not suitable for crop production.	High levels of agricultural technology; potential increase of crop yields in 2050 by a factor 2.9 - 4.6; feed efficiency between 0.07 to 0.32 kg product per kg dm feed.	Regional, crop yields from grid cell model	Crop yields depend on the productivity of land	Regional FAO projections for food demand include fourteen food product groups (e.g. cerals, bovine meat); feed demand from IMAGE model, depending on feed composition factor (i.e. grasses and fodder, crops, residues, scavenging) and feed conversion efficiency. Production of crops is allocated to areas with suitable agro-ecological condittions. 3 scenario projections for industrial roundwood and woodfuel demand used, while other wood is available for bioenergy.
8	Bottom-up modeling of different food demand	scenario analysis of vegetarian, moderate, affluent diet; levels in grain equivalents	High and low level input system defined	Irrigated areas assumed to be constant; other yields are rain-fed	Arable land and grassland suitable for production, i.e. has no soil-related constraints based on NASA soil database	High level input system - external inputs maximised for crop yields; low level input system with best technological and ecological means (no chemical fertilisers and biocides, biological N-fixation)	potentials for for food production is estimated for 15 regions; crop production modelled per grid-cell	standard cereal and grass; yields are simulation with crop growth model LINTUL (Spitters, 1987 and 1990)	Ratio between food demand and supply is set to 1:2 to account for losses and other uses of food crops.

Table A1.5 Biodiversity in the biomass potential studies

No.	Methods	type soil	type farming system	land excluded	objective biodiversity	economic value
1	Exclusion of forest land, not explicitly for biodiversity	not specified	not specified	exclusion of forest land, which leads to reduction of about 2 EJ/yr in Eastern Europe 2 EJ/yr	none	none
2	Biodiversity and nature developments accounted for by using 'land claim exclusion factor'	not specified; pressure on land quality (e.g. nutrient resources, organic content soil) not included	different management factors, farming system not specified	nature development, urbanization (function of population growth), cattle grazing on extensive grass land and restland are excluded	nature development should be 10-20% of global area (now in IMAGE 6%) => scenario dependent increase of 5-15% assumed; nature developments on each land-use category; restland is excluded for 50% (90% in ecological scenarios)	none
3	Same scope for geographical potential as Hoogwijk A, costs are based on labor, capital and land costs	-	-	-	-	-
4	Natural adaptation indirectly included by assuming low intensive forestry	not specified	low intensive forestry with relative low yields	high elevation (>3500 m), high population density (>200 persons/km^2) and land with no net carbon uptake	not specified	indirect value as a production system with shorter rotations and artifical change of species would be more economic
5	Protection of already established park and wilderness areas	not specified	current agriculture, increase of no-tillage, increase of crop yields a.o. with genetic modification and higher inputs	Exclusion of forestland that is reserved from harvesting due to e.g. parks and wilderness	not specified	not specified
6	Carbon policy (rental contract) to avoid deforestation assumed in some scenarios,	not specified	low intensive forestry with relative low yields	protected areas as defined in the World database on protected areas not used of afforestation	not specified	indirect value as a production system with shorter rotations and artifical change of species would be more economic
7	exclusion of protected areas; demand for feed from pastures kept constant to avoid increasing grazing intensities.	not specified	Very intensive crop production systems	Protected forest areas excluded from wood production; Deforestation of natural forests for crop production excluded;	not specified	not specified
8	Consideration of low input production system, that is ‘best ecological means’	Not specified	Scenarios of high/low input systems	Only agricultural land taken into account	not specified	not specified

Table A1.6 Water in the biomass potential studies

No.	Methods	type irrigation	efficiency use	climate data	resolution	soil type (infiltration)	competition other uses	water quality
1	Comparison of reference evapotranspiration from climate data and actual evapotranspiration of crops (over growing periods)	none	not specified	Interpolation of CRU climate data [Climate Research Unit Norwich]	grid cell 0.5 degree	not specified with regard to infiltration	not taken into account	not taken into account
2	Rainfed yields from AEZ approach, indirect inclusion of irrigation in management factors (MF)	included in MF, but not specified	Net primary production assumes optimal water efficiency, reduced indirect by MF	Climate model within IMAGE, feedback of climate changes on rainfall	grid cell 0.5 degree	summarised in Agro-Ecological Zone model of FAO	depeletion of water not included	not included
3	not specified, biomass potentials from Hoogwijk A	-	-	-	-	-	-	-
4	Rainfed yields from net primary production	not taken into account (only forestry studied)	not specified	Indirectly included in net primary production	grid-cell (0.5 degree)	not specified	not taken into account	not taken into account
5	Assumption that future crop yields are based on selection to resist water stress	current situation	not specified from agricultural statistics	not specified	not specified	not specified	not taken into account	not taken into account
6	Rainfed yields from net primary production	not taken into account (only forestry studied)	not specified	Indirectly included in net primary production	grid-cell (0.5 degree)	not specified	not taken into account	not taken into account
7	Rainfed yields from AEZ approach, scenario analysis of irrigation	irrigation only if climate, soil and terrain are suitable (IIASA dataset)	not specified	included in AEZ data	total area suitable for irrigation not specified locally		not taken into account	not taken into account
8	Includes irrigation in the high input production system	not specified	not specified	database from Mueller, 1987	grid-cell (1 degree)	not specified	not taken into account	not taken into account

Table A1.7 Main assumptions on population, GDP and trade in the biomass potential studies

No.	Methods	Population	GDP	Trade
1	Assessment of eco-physiological biomass yields; excluding forestry land and land very suitable for cereals	not specified	not specified	not specified
2	Use of integrated assessment model IMAGE 2.2. Assessment of food and material demands and modeling of energy crops on grid cell level	SRES scenario assumptions: 8.7-11.3 billion in 2050, 7.1-15.1 billion in 2100	SRES scenario assumptions: 235-529 trillion USD95 in 2100	SRES scenario assumptions: very low to maximal
3	Top-down estimation of biomass cost supply curves using regional biomass potentials from Hoogwijk et al., 2005	SRES scenario assumptions: 8.7-11.3 billion in 2050, 7.1-15.1 billion in 2100	SRES scenario assumptions: 235-529 trillion USD95 in 2100	SRES scenario assumptions: very low to maximal
4	Demand driven analysis of bioenergy potentials and sink enhancement, evaluation of net present values (NPV) of forest production (including payments for carbon sequestration) compared to agricultural production	SRES scenario assumptions (A2 and B1)	SRES scenario assumptions (A2 and B1)	not specified
5	Bottom-up analysis of resources in forestry and cropland based on outlook studies from agriculture and forestry	UN and FAO projections: 37% growth in U.S. until 2050	not specified	export projections from USDA
6	Demand-driven analysis of land use change mitigation options on grid-cell level; methods similar to Obersteiner (NPV comparison)	Revised regional SRES scenarios	Revised regional SRES scenarios	not specified
7	Bottom-up modelling of potentials and review of existing potential studies	UN projections medium growth: 8.8 billion in 2050	not specified	no trade limits of crops and wood
8	Bottom-up assessment of food supply and remaining potentials for bioenergy	UN projections: 7.7-11.2 billion in 2050	not specified	no trade limits of crops

Table A1.8 Economic mechanisms in the biomass potential studies

No.	Methods	land prices	food prices	Feedstock and fuel prices	market mechanism	regional differences
1	Not taken into account	-	-	-	-	-
2	Food demands and supply are modelled in Agriculture-Economy-Model (AEM) of IMAGE, maximisation of utility using preferences, cost-supply curves of energy crops modelled in Hoogwijk et al.	Not specified	Indirectly included in AEM	Feedstock and fuel prices do not change due to biomass production, but are static depending on scenarios	trade of food between regions, food and fodder crops related to income)	GDP, trade etc. modeled for 17 regions
3	Biomass potentials from Hoogwijk et al. 2005 and establishment of cost-supply curves	land rental costs based on added value of land from World Bank (Kunte et al. 1998), land prices depend on scenarios	see Hoogwijk et al., 2005	see Hoogwijk et al., 2005	substitution elasticity (0.65-0.95) of capital and labour costs in energy crop production;	see Hoogwijk et al., 2005
4	NPV of land use as criteria for afforestation/ reforestation projects	land prices in Brazil are starting point (200-2000 USD/ha), other countries adapted with purchasing power parity.	Not specified	Forestry driven by stumpage timber and energy price (estimated from bounds in Brazil, applied to grid cells), discount rate and carbon prices, silvicultural production costs based on harvesting and trucking	population density as proxy for accessibility of markets and infrastructure of agricultural production	NPVs calculated on grid cell level
5	Future food demands directly linked to population increase	Not specified	Not taken into account	Not specified	Not taken into account	Not applicable
6	NPV of land use as criteria for afforestation/ reforestation projects as in Obersteiner et al., 2006	See Obersteiner et al., 2006	See Obersteiner et al., 2006	Price and demand trajectories for timber are a main driver	See Obersteiner et al., 2006	See Obersteiner et al., 2006
7	Not taken into account	-	-	-	-	-
8	Not taken into account	-	-	-	-	-

Table A1.9 Energy use in the biomass potential studies

No.	Methods	energy demand	role biomass	methods of model	tech. developments	non-energy use biomass
1	not taken into account	-	-	-	-	-
2	potential recalculated to either electricity or transport fuel (using BIG/CC and Fischer-Tropsch)	not relevant	not relevant	straight-forward conversion of biomass to energy carriers	long term developments (2050) assumed, chosen technologies not available	not taken into account
3	cost supply curve for transport fuel and electricity using transport and conversion costs	not relevant	not relevant	straight-forward conversion of biomass to energy carriers	long term developments (2050) assumed, chosen technologies not available	not taken into account
4	not taken into account	-	-	-	-	-
5	Estimate whether biomass potentials can might 30% of current US petroleum consumption	-	-	-	-	-
6	not taken into account	carbon and energy price trajectories from MESSAGE model	indirectly specified by preferences SRES scenarios	see MESSAGE (energy models)	see MESSAGE (energy models)	see MESSAGE (energy models)
7	not taken into account	-	-	-	-	-
8	not taken into account	-	-	-	-	-

Table A1.10 Sensitivity analysis done in the biomass potential studies

No.	parameters analysed	parameters discussed	scenarios	policy included
1	inclusion of miscanthus into energy crops => important in CEE, but not in FSU	research on optimal and highly productive plant materials for various environmental conditions	-	-
2	population (change from B1 to A1) => 250% increase of area GDP (change from B1 to A1) => area decreases slightly management factor => strong influence in the beginning (later off-set by learning) diet => increasing area by 290% learning => without marginal potentials, rest land exclusion factors => important	amount of abandoned land available for energy crops use of rest land questionable (ecosystems and water resources need more study) different agricultural production system (apart from general management factors)	SRES scenarios (trade level, meat consumption, technology development, management factor, fertilisation, crop intensity growth, population, GDP, social/environmetal priotising)	social/environmental priorities in scenarios
3	elasticity, and management factor (i.e. technology development) => high sensitivity	competition with food, ecological impact of large-scale plantations, possibilities in extensive production systems	SRES scenarios (see [2])	social/environmental priorities in scenarios
4	carbon and timber prices=> strong impact land prices => lower impact	time invariant prices, while shadow prices might increase over time biological growth patterns competition for land with food production due to expansion of afforestation activities biodiversity rural economies	A2, B1 from SRES scenarios	social/environmental priorities in scenarios
5	rates of crop yield increases	residues removals best estimated at field levels demand for meat and export demands for wheat and soybeans necessary changes in production system, forest accessibility transportation costs of wood labour availability available feed from by-products of biofuel production	agricultural technology and yields varied: 1 current availability, 2 technology changes for conventional crops, 3 technology changes and land use changes for perennial crops	Change to perennial crops systems and no-till systemst stimulated in scenarios
6	carbon prices => high: socio-economic parameters of scenarios not important, low: significant changes	refinement of biophysical forest growth modeling risks (fire, pests)	Using A2, B1 scenarios that are adapted to be spatially explicitly (A2r, B2r from Gruebler, forthcoming)	baseline scenario and a mitigation policy scenario (policy incentives in the form of carbon prices and higher bioenergy demands)

Continued Table A1.10

No.	parameters analysed	parameters discussed	scenarios	policy included
7	land allocation (best land to food or bioenergy) => potentials energy crops -13 to +22% forestry plantation establishment, population growth per capita food consumption technology change, demand for wood	geographically explicit land use data animal production system wood supply from plantations and trees outside forests supply from natural forest growth	Four production systems (assumed to be sufficient to meet growing food demands in 2050): (1) mixed animal prod, very high tech of crop production rain-fed, (2) mixed animal prod, very high tech of crop production rain-fed and irrigation, (3) landless animal prod, very high tech of crop production rain-fed and irrigation, (4) landless animal prod, super high tech of crop production rain-fed and irrigation	not specified
8	production system population diet agricultural land irrigation	biological N-fixation in low-input system (depends on management and soil characteristics) possibility of using all potential agricultural area constraints in production due to infrastructure, knowledge, economic and socio-cultural conditions demand for other biomass products (e.g. wood, paper) climate changes	High and low intensities of food and biomass production; different amount of agricultural land (present and potential); diets and population growth	Not specified

Appendix 2 Other recent biomass potential studies

The following recent biomass potentials studies have **not** been selected for our review:

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
Ericsson and Nilsson assessed biomass potentials in Europe from a supply based basis. In terms of land availability, percentages of total agricultural or set-aside area are assumed and concerning yields, learning factors are derived from historical experience with wheat. However, no modelling of water availability, food demands or macro-economic parameters has been carried out in this study. This study assesses energy crops as well as agricultural and forestry residues.

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.
Schneider and Mc Carl modelled biomass potentials in the US from a demand-driven approach, i.e. basing the amount of biomass produced on carbon prices and an equilibrium model. The results are expresses in GHG emission reduction and do not specify the energy potentials.

Gielen, D.J., J. Fujino, S. Hashimoto, and Y. Moriguchi, 2002, Biomass strategies for climate policies, Climate Policy 2, 319-333.
Gielen et al. estimated the use of biomass for energy and materials depending on regional carbon prices. Assumptions on the supply of biomass are not described. This demand-driven approach results in rather low bio-energy potentials of about 10 to 100 EJ in 2050.

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.
Van Dam et al. use a similar approach than Smeets et al. (2007) and estimated biomass potentials and supply costs for Eastern Europe applying land use data to a statistical Nut-3 level differentiation. The scenarios used for evaluation are oriented at the SRES scenarios.

Appendix 3 Studies of water resources

In this Annex 3 some leading studies with different approaches to water use and to bio-energy are discussed. Some of these are based on a water perspective without attention for bio-energy and some on a bio-energy perspective with attention for water, but in a setting of potentials and not actual situations. All types of studies are necessary to get the picture complete. Each of the studies has its own focus, which makes them difficult to compare in some aspects. However, we describe them as much as possible according to the format discussed.

The first three studies do not include the effects of energy crops on water use explicitly. They can be considered part of the agricultural system, but then at the expense of food, fibre and feed production. Subsequent studies have combined water use and bio-energy production.

Study : Shiklomanov, 2000

Overview of water resources and water use according to (Shiklomanov, 2000)→ appendix Table 1.

- Data: from 2500 hydrological stations in the world and collected monthly and annual meteorological data. The data refer to long-term observations (1921-1985), are spread over regions and river systems and are a measure for natural runoff. For regions without data (15-20% of the area) extrapolation was based on models and mapping techniques.
- The spatial scale: 26 natural-economic regions (i.e. regions with similar physiographic and economic conditions) and results are aggregated per continent.
- Time scale: trends in time are analysed (1921-1995) and extrapolated (2000-2025): taking into account population growth, development of industries and agriculture based on statistics
- Results:
- The table shows that looking at continental scale only, does not show the large regional differences within continents. In Africa, potential water availability varies between 710 and 28,800 m^3 per capita, with an average of 5720 m^3. Similar variation exists in Asia, while in South America variation is much less. Also the coefficient of variation, representing the year-to-year variation, varies per region. Especially in arid and semi-arid regions year-to-year variability is very large. In other regions, water availability is very high (Canada+Alaska, Oceania): 170,000 – 180,000 m^3 per capita and the annual variation is very small.

***Study 2: Vőrősmarty et al., 2000*:**

- Goal: indicate influence of population growth and climate change on water availability
- Spatial scale: more detailed picture: 30' grid cells → n= 59.100 regions
- Water Balance Model was used. → ? based on statistics and trend extrapolation
- Model calculates runoff and river discharge,
- Time horizon: 1985-2025
- Assumptions and data used:
  - Monitoring data for runoff used, converted to discharge for digitized rivers
  - Country level water withdrawal statistics.
  - Domestic and industrial water use: statistics
  - Population per capita statistics: 1 km^2 data sets
  - Future development population and water use efficiency based on projections of % change
  - Scenarios for population growth and climate change (IPCC based) and combinations

Confirms largely the results of Shiklomanov, but with more regional detail

Study 3: Comprehensive Assessment of Water Management in Agriculture (in prep) Ch 3 Trends CA-water, Rainfed Agriculture

An assessment on present and future water use, based on measurements, observations, expert judgement. Indicates water resources and use for human purposes. Historical analyses and prediction of future trends. Very broad data basis (a.o. Shiklomanov, Vőrősmarty).

Growth in crop production: expansion of cropping area, on to marginal lands
Increasing production per ha. → increasing water use
OECD countries high water use due to industries
In Middle East/North Africa water use high due to irrigation
Sub Saharan Africa very high variability

Study 4: World Water in 2025 (WaterGAP)- Alcamo et al.

- Aim: science-based review of global water resources from a long term perspective, based on a set of integrated models and linking science with policy
- Spatial scale: 0.5'x 0,5' → 67,000 grid cells
- Time scale: averages over 30 years for climate, daily integration step,
- Time horizon: 1995-2025
- Water availability model = river runoff + groundwater recharge;
  - includes physical and climate factors
  - daily soil water balance
  - daily canopy balance
  - daily water balance for open water (lakes + storage reservoirs)
  - lateral transport between grid cells
  - effect of changing land cover: rooting depth and albedo effect of changing climate: temperature, radiation, precipitation → not done
  - calibration and validation done: OK
- Water use model: water withdrawal
  - **Domestic:** historical data based on Shiklomanov:
    Assumed efficiency improvement factor; minimum requirement per capita*
    population → total dom. use per country
    allocation to grid cells based on population per grid cell → aggregation to river basins
  - **Industry:** similar to domestic
    historical data * efficiency improvement * electricity use → country use → allocation to grid cells based on population
  - **Agriculture:** livestock: nr livestock* water use per head
    irrigation: net = Etp
    gross = water withdrawal from resource
    data: digital map on irrigated areas (Döll & Siebel, 1999)
    calculations: rice – no-rice crops, nr growing seasons, total irrigated area, soil suitability paddy rice, long-term average temp, harvested area
    daily net irrigation requirements: ETp – Pavailable
    gross irrigation: field efficiency 0.35 (South East Asia) – 0.70 (Canada, North Africa → based on project level irr. Efficiency
    Validation→ OK
    scenarios: future extent of irrigated area, distributed over grid cells
- **Main uncertainties:**
  - Computed water withdrawal in developing countries
  - Computed water availability for areas without measurements
- Results: present and future water withdrawal and availability
- ratio: indicator water stress: > 0.4 → stress, as average value large risks for water shortages during part of the year.
- 0.4 seems low: reuse is not taken into account
- 0.4 in ind. countries not so bad → buffers and cleaning water (recycling) in developing countries worse: no cleaning, no buffering → no recycling

Study 5: Wolf et al, 2003; Luyten, 1995

- Goal: compare food production and demand and assess scope for energy crops, taking into account water resources and water use.
- Spatial scale: calculations on a 1^o-1^o grid basis (n=15.400) and aggregated to 15 regions in the world,
- Time scale: 2040, static
- Agricultural systems: 2 practices, both good management

  - High input systems (HEI): maximum crop production, limited by water if no irrigation is possible
  - Low input systems (LEI): limited by water and nitrogen (only fixation), yield reduction due to pests and diseases of 10%
- o Crop growth model: LINTUL
  - based on light use efficiency
  - time step: 1 day
  - temperature-dependent length of growing season
  - nutrient use efficiency
  - Grass and grain as standard crops
- o Water limitation: soil water balance model for free draining soils
  - daily rate of change in soil moisture
  - Evapotranspiration (ET): ETREF based on temp and radiation (Makkink) for standard crop, multiplied by factor for canopy cover
  - Soil evaporation and percolation taken into account
  - Actual transpiration calculated from available water
  - AT/ET is reduction factor for crop growth
- o Databases:
  - global weather database Mueller, 1987 (monthly average weather data, many stations)
  - global soil database NASA, 1986 (digitized soil map of the world FAO) 1^{o}-1^{o} grid basis
  - land suitability assessment based on NASA data: fraction of land suitable for mechanized cultivation, 1^{o}-1^{o} grid basis
- o Assumptions:
  - Best technical means, based on Dutch agricultural practices
  - No socio-economic aspects
  - No restriction on land use change
- o scenario's:
  - 3 diets: vegetarian, moderate, affluent (food security = demand*2)
  - 3 population growth rates: low, medium, high
  - Comparison present and potential agricultural land
- o Results:
  - depending on the scenario scope for energy crops varies from nothing (LEI, all pop. growth rates, present land use) to 45% of present agricultural land use, covering food demands
  - compared to other sources: yields per ha of the energy crops (= yield of food crops) are realistic compared to the FAO statistical database; low compared to other studies on energy crop yields.
  - Areas available for energy crop production are very high compared to other studies

Potential agricultural area increase 50% compared to present → very high, nature, forests
Effect of climate change: not included in calculations
Total rainfall is expected to increase, but also variability is, drought spells may be longer in some regions → strongly regionally determined effects.
This study presents the potential and not the plausible development

Study 6: Berndes, 2002; PDMM

- o Goal: implications of large scale bio-energy production for water use and supply
- o Spatial scale: country and aggregation to global scale
- o Time scale: 1995, 2075, annual change rates
- o Method:
  - WUE at a ha basis for different crops: literature survey (Appendix Table 2)
  - assumed constant over regions and time.
  - ET at global scale for various scenarios from IIASA/WEC, based on WUE of 25 Mg/GJ feedstock. However, actual WUE can hardly be assessed. Depends on too many factors with large variation. Hence, less detail than the previous study on crop water use
- o 2 scenario's: irrigated energy crops, rainfed energy crops
  - Water withdrawal for food supply is according to a scenario of Alcamo(1977) → to be looked at. Data are modified for bio-energy production required according to a scenario IIASA/WEC scenario.

- Berndes tries to connect water use for food and fuel crops, water competition in 2 ways:
  - irrigation of energy crops + processing water
  - increasing ET on land for energy crops, which redirects runoff water and reduces downstream availability.
- The results
  - Growing energy crops shows similar trends as in the other studies mentioned for food crops, but much stronger: increasing water scarcity in most regions, with the largest effects in the regions that are under water stress already.

Study 7: EEA report7, 2006

- Goal: Analysis of environmentally-compatible potential of bio-energy for Europe
- Spatial scale: country, for whole of Europe
- Time scale: 2010-2020-2030, annual change rates
- Assumptions:
  - env. compatible bio-energy: the technically available for energy generation based on the assumption that no additional pressure is exerted on biodiversity, soil and water resources, taking into account current and future policies.
  - 30% farming with high natural values, i.e. low intensity→ lower crop yields
  - Present area under bioenergy crops and set aside land available for bioenergy crops
  - For environmental pressure (including water) : ranking of crops on a qualitative basis: ecological prioritisation study of energy crops for German conditions, literature review and expert knowledge
  - Crop choice in semi-arid areas aims at crops with low water demands, needing no irrigation
  - Story lines for scenario development
- Models used:
  - CAPSIM: partial equilibrium model for agricultural development including policies, all countries
  - HEKTOR: for 2 countries, parallel bottom-up approach: calculates area land needed for self-sufficiency for food and feed
- Results
  - Leaching of nutrients and pesticides is a serious problem
  - Water availability a problem in the Southern countries. In north 7% of the water use is by agriculture, in the south this figure is 50%.
  - land becomes available for energy crops due to CAP reforms and increases in crop productivity
  - Per country large differences: Netherlands, Belgium, Ireland: zero Poland, Spain, Germany most land

Water: assessments are only qualitative A, B or C for water requirements with an expert story (generally not irrigated, high water use efficiency, requires deep soils, etc. Appendix, table 3).

Parameters
In the studies involved many factors influencing water use and water productivity are <u>**not**</u> addressed:

1. Water management (type of irrigation system).
In most studies, water use is estimated on the basis of statistical data. For irrigation an overall efficiency is used, e.g. 50%. This gives an average, but very coarse picture. Improvements in WP in both irrigated and rainfed systems are often mentioned as an option for alleviating water stress. However, if this is improved it means that more water is used within the irrigation system, but less is conveyed to downstream areas. Hence, this is an important factor, it greatly varies among systems and locations and has inter-regional relation. A multi-scale approach is recommended.

2. Efficiency of water use due to management of production systems
In the large scale studies this is more or less included in the first parameter and no distinction is made between type of irrigation and management. Wolf et al indicate that they use the best technical means, i.e. a high efficiency of water use.

3. Weather data

All studies are based on rather detailed weather data on rainfall, evapotranspiration, temperature and radiation. These data are reasonably well documented, although not in the same detail everywhere in the world. Sometimes they are available on a monthly basis, sometimes only annual. As distribution over the year of all weather characteristics greatly influences crop growth potentials, these data should be collected with as much detail as possible.

4. Soil type

Soil type in itself is hardly ever mentioned in the studies. Only in the simulation study it is taken into account via soil water availability.

5. Climate change

Vőrősmarty takes into account climate change according to the CGCM1/WBM scenario. This implies a temperature rise.

6. Competition with water for other sources

In all studies either total water use is considered or priority is given to domestic and industrial use. The competition in itself is not worked out

7. Water quality

Water quality is not taken into account. Only in relation to waste water from domestic and industrial sectors it is mentioned as an item that needs more attention. Qualitative remarks are made, but no quantification is available. Emissions from agriculture are not considered.

Appendix 4 Modelling mechanisms, spatial and temporal scales of the different studies

a. Global scenarios

No.	Name	Organi-sation	Publication(s)	Key methodology	Spatial scale	Time scale
1	IGSM/EPPA	MIT	(Clarke et al., 2006) (Paltsev et al., 2005) (Babiker et al., 2001)	The MIT Emissions Predictions and Policy Analysis (EPPA) model is a recursive-dynamic multi-regional general equilibrium model of the world economy	Global, with 16 specified regions	2100
	1a	EPref		Reference scenario (from Paltsev et al[8])		
	1b	EPstab		Stabilisation scenario to 450 ppm CO_2 (from Paltsev)		
2	GET	Chalmers	(Azar et al., 2003) (Azar et al., 2006) (Grahn et al., submitted)	GET is set up to meet exogenously given energy demands while meeting a specific atmospheric CO_2 concentration target of 400 ppm, at the least energy system cost	Global	2100
3	WEM	IEA	(IEA, 2006b) (IEA, 2006a)	The world energy model mimics the functioning of energy markets. It has five modules: final energy demand, power generation, refining and other transformation, fossil fuel supply and CO_2 emissions.	Global, with 8 main regions	2030
	3a	WEMref		Reference scenario		
	3b	WEMaps		Alternative policy scenario		
4	TIMER	MNP	(Vuuren, in press) (Vuuren, 2006)	TIMER is an energy-system model that describes future energy use on the basis of relative prices of different technologies. TIMER has been used in the selected papers to describe a reference scenario and a low GHG stabilization scenario.	Global, with 17 world regions	2100
	4a	TIMref		Reference scenario		
	4b	TIM450		Stabilisation scenario leading to 450 ppm CO_2		
5	Message	IIASA	(IPCC, 2000)	MESSAGE is a dynamic linear programming model that calculates least-cost supply given resource availability, technologies, and energy demand. It iteratively matches effects of energy prices on GDP and energy demand	Global, with 11 regions	2100
	5a	MESa1b		Consistent with the SRES A1 Balanced scenario		
	5b	MESb1		Consistent with the SRES B1 scenario		
6	BEAP	NIES	(Gielen et al., 2003)	The Biomass Environmental Assessment Program simulates markets in energy, materials and food, and simulates an optimal situation in which consumer/ producer surplus is maximised. Global policy scenario.	Global	2040

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[8]: The scenarios in Paltsev et al. (2005) are merely illustrative. Clarke et al. (2006) contains a broader set of scenarios. However, since the scenarios in Paltsev et al (2005) where somewhat more clearly specified, and the scenarios and their outcome are mutually consistent between the two sources, we used Paltsev et al (2005).

b. EU Scenarios

No.	Name	Organi-sation	Publication(s)	Key methodology	Spatial scale	Time scale
7	Primes	NTUA	(Mantzos and Capros, 2006) (Uyterlinde et al., 2004) (Uyterlinde et al., 2005) (Capros, s.d.)	PRIMES is a behaviour- and price-driven partial equilibrium model of the EU energy system, iteratively matching energy demand and supply.	EU25/EU15	2030
7a	PRIbas			Baseline scenario		
7b	PRIhr			HighRenewables + Energy Efficiency Scenario		
8	Markal	ECN	(Uyterlinde et al., 2004) (Uyterlinde et al., 2005)	MARKet ALlocation is a family of dynamic bottom-up energy system models, mostly based on linear programming, optimizing on least total energy costs.	EU15	2050
8a	MAref			Reference scenario		
8b	MArs			High (20%) renewables scenario		
				Possibly added: POLES, ChalmersVIEWLS, or others from CascadeMints		
9	PGG	ECN	(Rabou et al., 2006)	Analysis of technical feasibility of an overall 30% biomass target in the Netherlands, and allocation over applications, taking into account e.g. depreciation and replacement rates of current fossil-based capacities	NL	2030

Appendix 5 Assumptions on population, GDP, energy demand

a. Global scenarios

No	Name	Population	GDP /cap (PPP), and growth rate	Energy demand in final year of the model
1a	EPref	UN (2000, 2001) forecasts: 10 Billion people in 2100	72,200 \$(1997)[9] /yr in 2100 2.1% /yr	1330 EJ/yr[9] (of which 220 EJ/yr for power generation)
1b	EPstab	Ditto	Not clearly specified, probably lower than in EPref	950 EJ/yr (of which 180 EJ/yr for power generation)
2	GET	Not specified	Not specified	680 EJ/yr: 170 EJ/yr for power, 160 EJ/yr for transport
3a	WEMref	UN (2004 revision): 8.1 Billion people in 2030	17,196 \$(2005)/yr in 2030 3.4% /yr; from OECD/World Bank/IM	715 EJ/yr
3b	WEMaps	Ditto	Ditto	645 EJ/yr
4a	TIMref	Ditto	35,968 \$(95) / yr in 2100. 1.9%/yr	1342 EJ/yr
4b	TIM450	Ditto	35,968 \$(95) / yr in 2100. 1.9%/yr	1106 EJ/yr
5a	MESa1b	Harmonised for the SRES scenarios: 7 Billion people in 2100	72,800 \$('90) /yr in 2100 2.6%/yr	
5b	MESb1	Ditto	45,200 \$('90) /yr 2.1% /yr	2700 EJ/yr
6	BEAP			670 EJ/yr

b. EU scenarios

No	Name	Population	GDP	Energy demand (EJ/yr)
7a	PRIbas	469 Million people in 2030	34,200 EUR ('00)/yr in 2030 2% /year	79
7b	PRIhr	Ditto	Ditto	64
8a	MAref	Consistent with IPCC/SRES marker scenario B2		72
8b	MArs	Ditto		66
9	PGG	Not specified	Not specified	3

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[9] Endogenously modeled, so output, not exogenous input to the model

Appendix 6 Biomass shares and allocation

a. Global scenarios

No	Name	Biomass share in total supply (EJ/yr)	Power (EJ/yr)	Transport (EJ/yr)	Other (EJ/yr)
1a	EPref	140 (10%)	0	?	140?[10]
1b	EPstab	250 (25%)	0	?	250?
2	GET	200 (30%)	30 (17%)	0	170
3a	WEMref	69 (10%)	6 (9%)	10 (14%)	53 (77%)
3b	WEMaps	71 (11%)	8 (11%)	15 (21%)	48 (68%)
4a	TIMref	248 (18%)	161 (65%)	29 (12%)	58 (23%)
4b	TIM450	404 (37%)	37 (9%)	197 (49%)	170 (42%)
5a	MESa1b	475 (18%)	Not specified		
5b	MESb1	235 (31%)	Not specified		
6	BEAP	242 (36%)	0	210 (86%)	32 (14%)

b. EU scenarios

No	Name	Biomass share in total supply (EJ/yr)	Power generation (EJ/yr)	Transport (EJ/yr)	Other (EJ/yr)
6a	PRIbas	6.2 (8%)	2.9 (47%)	1.5 (24%)	1.8 (29%)
6b	PRIhr	11.6 (18%)	5.6 (48%)	3.9 (34%)	2.1 (18%)
7a	MAref	9 (12%)	5 (60%)	1 (10%)	3 (30%)
7b	MArs	17 (25%)	2 (13%)	14 (84%)	0.5 (3%)
8	PGG	0.91(23%)	0.12 (13%)	0.35 (38%)	0.44 (49%)

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[10] In both EPPA scenarios, it remains relatively unclear where the biomass is applied. According to the graphs, it is not allocated to power generation. According to the text in Paltsev et al. (2005) and Clarke et al (2006), it partly goes to transportation fuels, partly to heat, but these shares are not further specified.

Appendix 7 Assumptions on policies

a. Global scenarios

No	Name	General climate policies		Specific policies on power and heat		Specific policies on the transport sector	
		CO_2 cap	CO_2 taxation	Option 1	Option 2	Option 1	Option 2
1a	EPref	No specific policies in any sector					
1b	EPstab	Eq. to 550 ppm resulting CO_2 emiss: Ca 6.7 GtC (2010) Ca 9 GtC (2040) 5 GtC/yr	Resulting from cap: 40 $/tC (2010) Ca 200 $/tC (2050) Ca 1500 $/tC (2100)				
2	GET	Eq. to 400 ppm					
3a	WEMref	Only policies currently in place		E.g. EU 2010 target			
3b	WEMaps	Current policies and proposed ones. EU: BAP: 150 Mtoe biomass by 2010 New sectors in EU-ETS And other relevant national policies		Current policies and proposed ones. US: RES portfolio standards per state And other national policies		Current policies and proposed ones. US: 7.5 Bill. Gallons in 2012 EU: 5.75% in 2010 And other national policies	
4	Timer						
5a	MESa1b	Not specified, but policies will be consistent with a1b storyline: increased globalisation, more markets, and balanced fossil/renewable					
5b	MESb1	Not specified, but policies will be consistent with b1 storyline: increased globalisation, more governmental coordination					
6	BEAP	Generic climate policy: CO_2 penalty increasing from 10 $/ton CO_2-eq in 2005 to ca 80 $/ton CO_2-eq in 2020					

b. EU scenarios

No	Name	General climate policies		Specific policies on power and heat		Specific policies on the transport sector	
		CO_2 cap	CO_2 taxation	Option 1	Option 2	Option 1	Option 2
7a	PRIbas	Further liberalisation of energy markets ETS with CO_2 price of 5 €('00)/ton CO_2 No post-2012 targets		Further deployment of gas-based (CH)P NMS moving away from coal Current RES-E policies		Current Efficiency targets for new cars Current targets of biofuels directive	
7b	PRIhr	Proposed new sectoral policies and targets, plus a generic 'renewables value' that mimics a feed-in tariff, set at 35 €('05) per MWh					
8a	MAref	€ 10 per ton CO_2 tax for all sources		18% RES in power generation			
8b	MArs	Carbon cap for industry: 200 Mton CO_2		33% RES in power generation		CO_2 tax on fossil fuels of € 0.33 /l	
9	PGG	Not specified					

Appendix 8 Assumptions on technologies and costs: power generation

a. Global scenarios

No	Name	Fossil option(s)		Biomass option(s)			Other alternative(s)	
		Primary feedstock	Conversion	Primary feedstock	Conversion	Conv. efficiency	Primary feedstock	Conversion
1a	EPref	Prices endogenous (reserves, policy) Reserves specified: Oil: 35,000 EJ Gas: 19,000 EJ Coal: 179,000 EJ	Not specified in literature	Biomass has a mark-up factor of 1,4 to 2,0 compared to fossil competitor		40%	Solar, Wind NGCC NGCC with CCS CGCC with CCS Coal Gas Shale oil	Mark-up factor of 1.0 to 4.0 Mark-up: 0.94 Mark-up: 1.16 Mark-up: 1.19 M-u: 3.5-4.0 M-u: 2.5-2.8
1b	EPstab				Ditto		Ditto	
2	GET	Coal: 2 $/GJ Oil: 3 $/GJ Gas: 2,5 $/GJ[11]		Biomass: 3 $/GJ, max 200 EJ/yr			Solar-H_2: 18 $/GJ	
3a	WEMref	Coal: 4.1 to 5.8 $(’05)/kWh Gas: 5.0 to 6.5 $(’05)/kWh		Based on Green-X methodology: dynamic cost-resource curves. No further data specified			Wind onshore	5.0 – 7.5 $(‘05)/kWh
3b	WEMaps	Ditto		Ditto			Ditto	
4	Timer							
5a	MESa1b		Coal: 5-8 $(’90)/GJ NGCC: 2 $(’90)/GJ	Not found	5-7 $(’90)/GJ		Wind Other RES-E	5 $(’90)/GJ 4-8 $(’90)/GJ
5b	MESb1		Coal: 6-8 $(’90)/GJ NGCC: 2.5 $/GJ		4-6 $(“90)/GJ		Wind Other RES-E	5 $(’90)/GJ 3-7$(’90)/GJ
6	BEAP	7.5 $/GJ		2.5 $/GJ, totalling to 10.5 $/GJ		45%	Not specified	

b. EU scenarios

No	Name	Fossil option(s)		Biomass option(s)			Other alternative(s)	
		Primary feedstock	Conversion	Primary feedstock	Conversion	Conv. efficiency	Primary feedstock	Conversion
7a	PRIbas	Coal: 2.4 $ (’05)/GJ Gas: 7.3 $ (’05)/GJ						
7b	PRIhr	Ditto						
8a	MAref							
8b	MArs							
9	PGG	Not specified						

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[11] Probably a typo in the report; possibly 5 $/GJ was meant

Appendix 9 Assumptions on technologies and costs: transportation

a. Global scenarios

No	Name	Fossil option(s)		Biomass option(s)			Other alternative(s)	
		Primary feedstock	Conversion	Primary feedstock	Conversion	Conv. efficiency	Primary feedstock	Conversion
1a	EPref	Oil: 35,000 EJ	Not specified	Biomass has a mark-up factor of 2,1 compared to fossil competitor		40%	Shale oil	M-u: 2.5-2.8
1b	EPstab				Ditto		Ditto	
2	GET	Oil: 3 $/GJ		Biomass: 3 $/GJ, max 200 EJ/yr			Solar-H_2: 18 $/GJ	
3a	WEMref	Oil: 8 $('05)/GJ		Not specified			Not specified	
3b	WEMaps							
4	Timer							
5a	MESa1b				3 $('90)/GJ			Coal synf: 4-6 $('90)/GJ Gas synf: 1.5 $('90)/GJ
5b	MESb1				3 $('90)/GJ			Coal synf: 5-7 $('90)/GJ Gas synf: 2 $('90)/GJ
6	BEAP	Gasoline: 3.4 $/unit Diesel: 2.5 $/unit		Cellul to EtOH: 8.5 $/unit Wood to FT-diesel: 10.2 $/unit		50% 50%	Not specified	

b. EU scenarios

No	Name	Fossil option(s)		Biomass option(s)			Other alternative(s)	
		Primary feedstock	Conversion	Primary feedstock	Conversion	Conv. efficiency	Primary feedstock	Conversion
7a	PRIbas	Oil: 9.4 $('05)/GJ						
7b	PRIhr	Ditto						
8a	MAref							
8b	MArs							
9	PGG	Not specified						

Appendix 10 Assumptions on technologies and costs: other sectors

a. Global scenarios

No	Name	Fossil option(s)		Biomass option(s)			Other alternative(s)	
		Primary feedstock	Conversion	Primary feedstock	Conversion	Conv. efficiency	Primary feedstock	Conversion
1a	EPref	Not specified[12]						
1b	EPstab	Not specified						
2	GET	Not specified						
3a	WEMref	Not specified						
3b	WEMaps	Not specified						
4	Timer							
5a	MESa1b	Not specified						
5b	MESb1	Not specified						
6	BEAP	Heating: gas residential: 2.1 $/unit Heating: gas industrial: 17 $/unit Coal material feedstock: 0.6 $/unit Plastic: polyethylene: 170 $/unit		Wood heating residential: 5.2 $/unit Wood heating industrial: 38 $/unit Charcoal material feedstock: 5.9 $/unit Plastic: polyactic acid: 220 $/unit		67% 71% 72% 80%	Not specified	

b. EU scenarios

No	Name	Fossil option(s)		Biomass option(s)			Other alternative(s)	
		Primary feedstock	Conversion	Primary feedstock	Conversion	Conv. efficiency	Primary feedstock	Conversion
7a	PRIbas	Not specified						
7b	PRIhr	Not specified						
8a	MAref							
8b	MArs							
9	PGG	Not specified						

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[12] EPPA does specify the elasticity between energy use in transportation versus other consumption, which is set at 1.0.

Appendix 11 SCENAR 2020

The SCENAR 2020 project has been organised in two phases. Figure A11.1 shows the structure of the study.

The first phase established the basic data set, in terms of trends drivers and their likely projection into the future. On the basis of this data, three scenarios were established that highlight what impact these trends will have on the rural world and the agricultural economy.

The analysis of the state of agriculture practice and the rural economy within the EU on the horizon of 2020 is within a 30-year framework. The first period, 1990-2005, is the benchmark for the second period, 2005-2020. As indicated in Figure 1.1, trends in have been verified according to a review of primary data; the purpose is to distinguish long-term tendencies that are for the most part a reflection of driving forces that are independent of policy influence, on the one hand, and the driving forces for shaping the rural world that are directly associated with agricultural and environmental policies, on the other.

The analysis of the trends and drivers were reviewed by a group of internal experts to advise the project team. A proposal for a principal scenario and a few alternatives were established. These scenario assumptions were then examined by a steering group of Commission services, their invited experts and the project team to jointly agree on the scenarios to be tested.

The second phase of the work began by a simulation of the likely effects at a sub-national territorial level (a combination of NUTS 3 and 2 regions). Two separate areas of simulation occurred: the rural population and economy, and the agricultural sector. As can be seen from Figure A1.1, a series of interdependent factors was analysed in each area, possibly requiring several iterations of simulation.

After the simulation process was complete, the internal expert group validated the results. The purpose of the simulation has been to permit an identification of clusters of regions having a similar evolution over time, in reference to each scenario. Once this clustering took place, a SWOT analysis was carried out with regard to each scenario. Conclusions were then developed as to the possible situation across the EU, on the horizon of 2020, with regard to demographic developments, the dynamics of rural economies and the future of the rural economy. These initial conclusions were reviewed by the steering group of Commission services, their invited experts and the project team. This current report constitutes the final version of the ‘technical study’. It will be followed by a summary document.

The reader is invited to consider that this scenario study on the future of agriculture and the rural world is not a ‘crystal ball’ for forecasting the future with exactitude. Rather, it provides a set of reasonable assumptions to help thinking about the future before having to decide upon appropriate courses of action and their accompanying policy framework. The reader is also reminded that the scenarios chosen for elaboration have characteristics that could have been different. Certain choices were made through consultation, but some readers would perhaps have preferred other orientations to have been taken, even if only in details; such a possible shortcoming is an inherent feature of any scenario study.

What this scenario study is intended to do that will be useful to all readers, however, is to highlight the relationships between the different land uses studied. The scenario study examines the contrary tendencies and the synergistic ones, and therefore should be useful in thinking about decisions that concern real or potential conflicts of interest in various social demands upon policy makers. As an example, the reader may wish to reflect upon the often-evoked apparent dilemma between policies that favour the sound management of natural resources (and nature conservation), which can be a positive externality of agricultural land use, and the necessity to reduce production costs in order to be competitive in an increasingly global market place, which can lead to environmental disturbance that is associated with certain forms of agricultural practice. Sometimes a good presentation of an issue can facilitate its resolution in a win-win manner, and certainly this is the ultimately satisfying use of a scenario study.

With all the *caveats* taken into account, it is hoped that the reader will find personal utility in referring to the contents of Scenar2020 – a scenario study on the future of agriculture and the rural world.

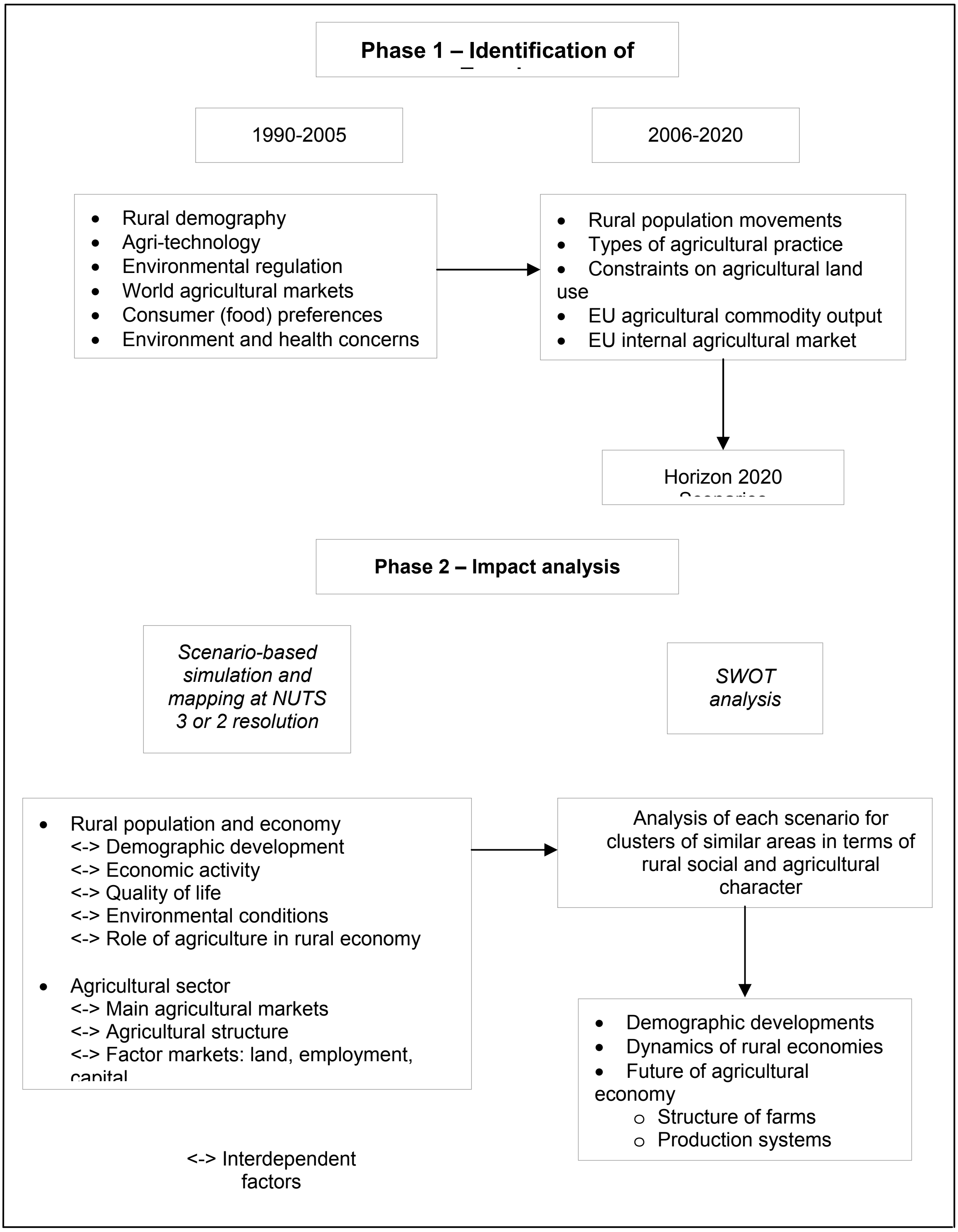

Figure A11.1 Structure of the SCENAR 2020 study

Appendix 12 LEITAP Scenario Results

This annex 12 describes the global implications of three scenarios:

1. Baseline which describes the results of a most probable scenario until 2020
2. Regionalisation with no agreement in the WTO Doha trade negotiations and high level of support for agriculture and
3. Liberalisation with full trade liberalisation and a full withdrawal of direct payments to farmers) on the macro-environment, sectoral production, international trade, income, employment and other factor markets.

The results are obtained with the LEITAP model. For expositional convenience we used the following regional and sectoral aggregates in the text and Figures:

Regional aggregates:

EU-15:	Individual EU-15 countries
EU-10:	2004 accession countries
EU-3:	EU applicant countries: Bulgaria, Romania and Turkey
HDC:	High developed countries: US, Canada, Oceania and Japan
C&S America:	Central and South America
Asia:	Asia
Africa:	Africa

Sectoral aggregates:

Crops:	grain, oilseeds, sugar, horticulture, other crops
Livestock:	cattle, pork and poultry (oap), milk
Processed food products:	sugar, dairy, other food processing industries (agro)
Agri-food complex:	Crops + livestock+ processed food products

Protected commodities:	grain, oils, sugar, cattle, milk, sugar, dairy
Other commodities:	horticulture, other crops, pork and poultry,[13] other food processing industries

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[13] In the GTAP database pork and poultry are aggregated into one category and cannot be separated. The less protected pork sector is combined with the poultry sector that is protected with import tariffs. For this aggregation we have chosen to add the pork and poultry aggregate to the other sectors instead of the protected sectors.

Population and GDP

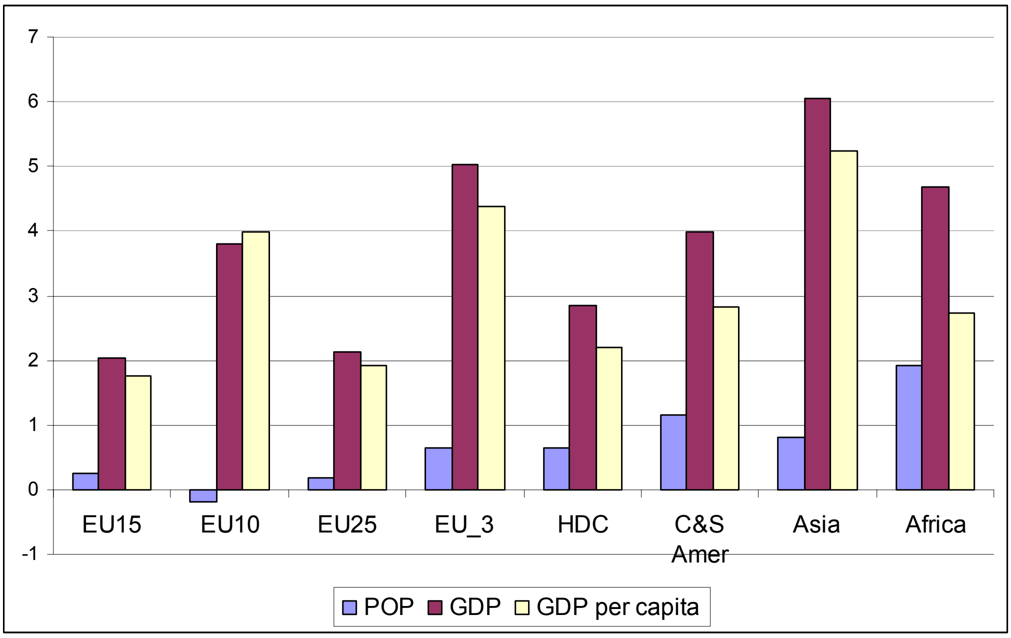

Figure A12.1 GDP, population and GDP per capita yearly growth rates (2005-2020).

Global population (exogenous)

Expected population developments in period 2005-2020:

- The world's population growth will fall from 1.4% in the 1990-2003 period to about 1% in the coming ten years. This is mainly due to births or fertility rates, which decline and are expected to continue to do so.
- Almost all annual population growth will occur in low and middle income countries, whose population growth rates are much higher than those in high income countries.
- Europe's share in world population has declined sharply and is projected to decline during the 21st century.
- Population growth in Europe is very low (0.3% yearly for EU-15) or slightly negative (-0.2% for EU-10)

Global GDP and GDP per capita (endogenous)

- Robust economic growth is expected over the coming period in almost all regions of the world in the baseline scenario (see Figure 1).
- Economic growth will be considerably higher for most of the transitional and developing countries than for the EU-15, the United States and Japan, in particular for Brazil, China, India and the new EU member states. Incomes in Europe are expected to increase slightly over the coming years.
- Income growth in Europe is about 2% yearly for EU-15 and 3.8% yearly for EU-10
- The process of transition continues in the accession countries (EU-10). Income growth is high (about 2 times that of the EU-15). The level of income is less than 50% of that of the EU-15 and there is ongoing structural change in their economies and especially in agriculture. Economic growth accelerates in the EU-10 after accession. Structural change will be supported by structural funds and rural development. The EU-15 economies are more saturated. The economies grow slowly and there are relatively stable structures in the whole economy.

Development of GDP

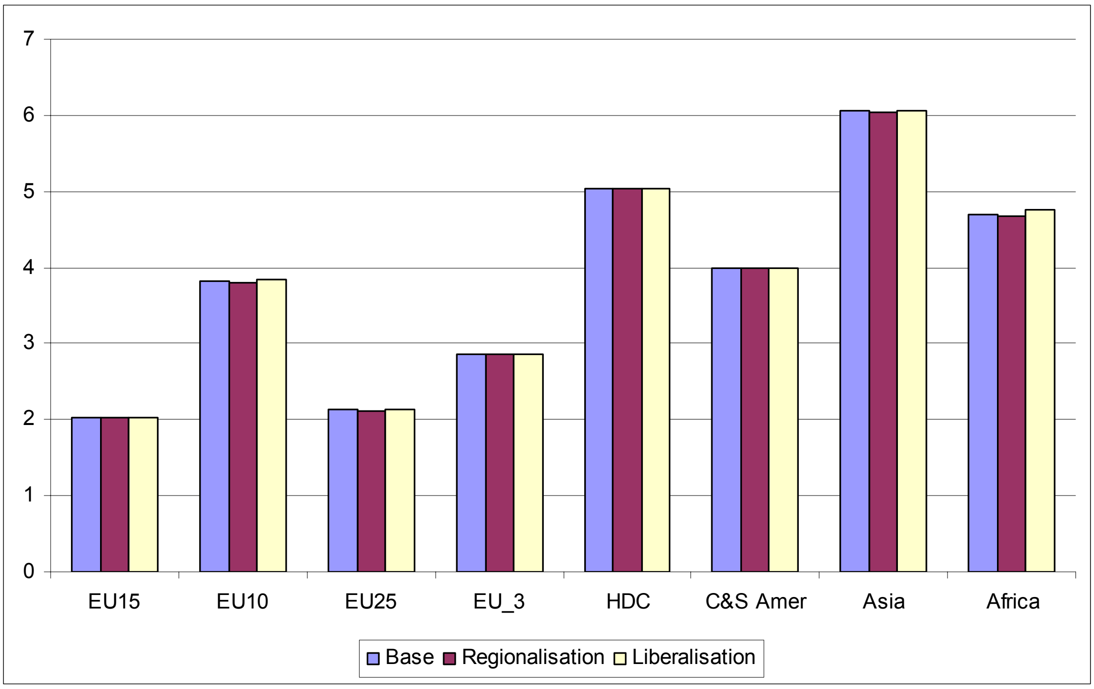

Figure A12.2 Real GDP growth in three scenarios, yearly growth rates (2005-2020).

- Real GDP is not very much influenced by the scenario assumptions. In all the scenarios it is mainly driven by the exogenous assumptions on technological change.[14]
- In general GDP growth is highest in the liberalisation scenario and lowest in the regionalisation scenario. The differences are highest in the developing countries.
- These results are conservative in the sense that only allocative efficiency effects are taken into account from abolishing or reducing import tariffs and export subsidies in agriculture and industries (market access in services is hard to quantify and not taken into account). The allocative efficiency effects related to agriculture and services are comparable to these calculated in the Francois et al. (2005) study (0.2% of world GDP).
- Francois et al. quantified also the impact of reducing estimated barriers in services and the possible expected benefits from trade facilitation due to liberalisation. Reducing these estimated service barriers adds 0.1% to world GDP growth and their assumptions that liberalisation leads to trade facilitation adds another 0.1% to world GDP growth. Despite these more speculative quantified benefits, the difference in world GDP growth in total is still only 0.5%. A World Bank study in 2003 obtained higher growth rates by including an assumption that trade liberalisation leads to higher productivity growth. Because the assumptions on services trade barriers, economies of scale and productivity spill-over effects are hard to quantify and very uncertain, we did not include these in this study.

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[14] The assumptions on technological change are determined in a pre-simulation where the values are the endogenous outcome of meeting GDP targets given exogenous estimates on factor endowments –skilled labor, unskilled labor, capital and natural resources- and population.

Sectoral shares in GDP

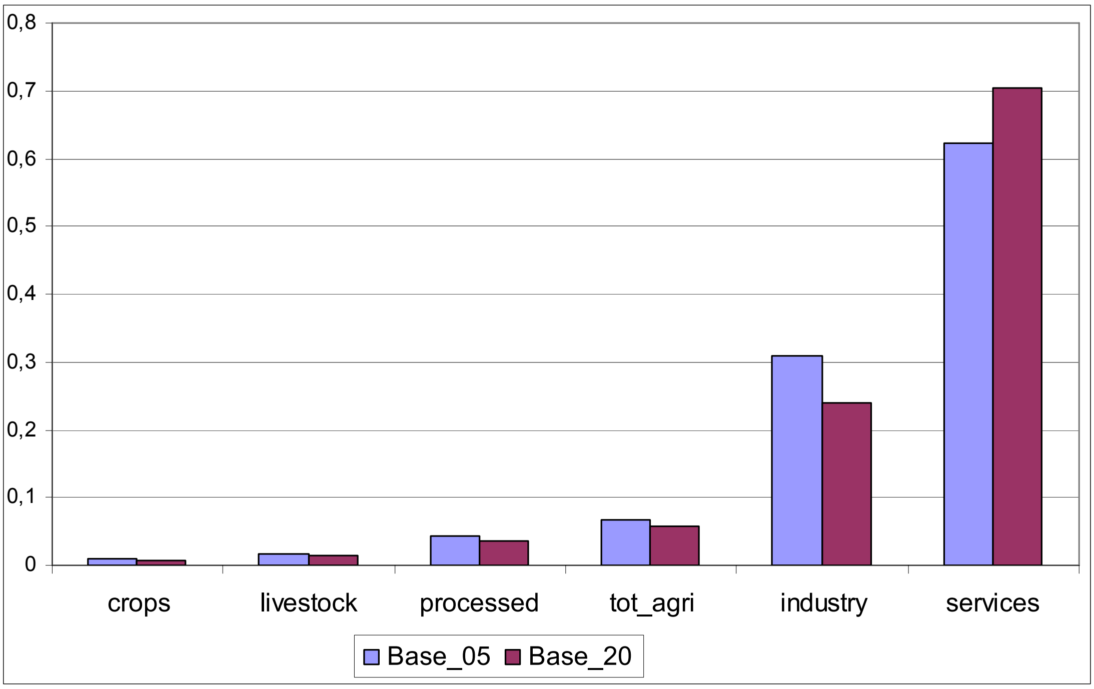

Figure A12.3 Sectoral structure of the economy in the EU-15 in 2005 and 2020.

- Figures A12.3 and A12.4 show that the process of structural change continues in the near future in the EU-15 and EU-10: share of agriculture and industries continues to fall and share of services continues to increase.
- The structural change process is more severe in the EU-10 than in the EU-15 countries.
- Regions with high shares of agriculture and industries may be vulnerable to this process with regard to employment and income growth, as the structural change process is often characterised by adjustment processes and related costs. It takes time that people adjust their skills, industries grow, etc. Also increasing and declining industries may be allocated in different areas.

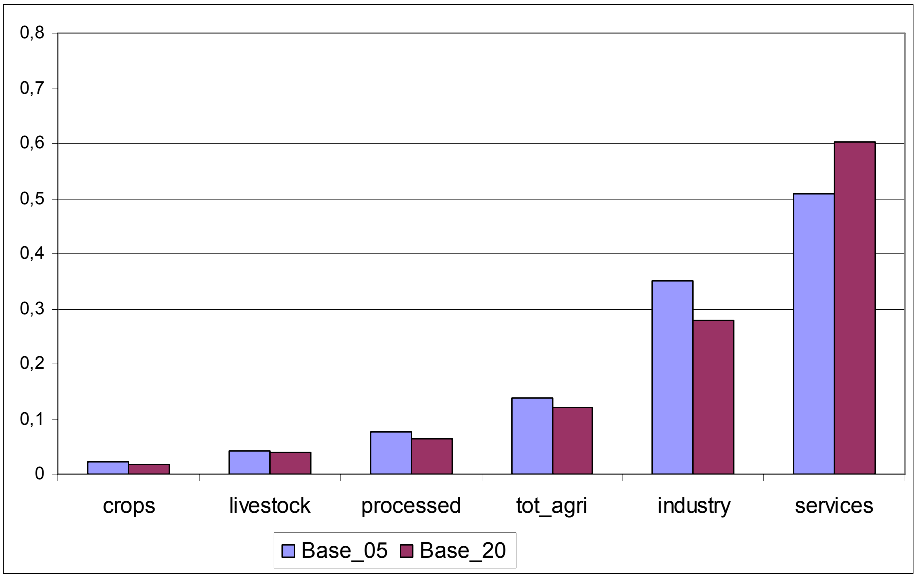

Figure A12.4 Sectoral structure of the economy in the EU-10 in 2005 and 2020.

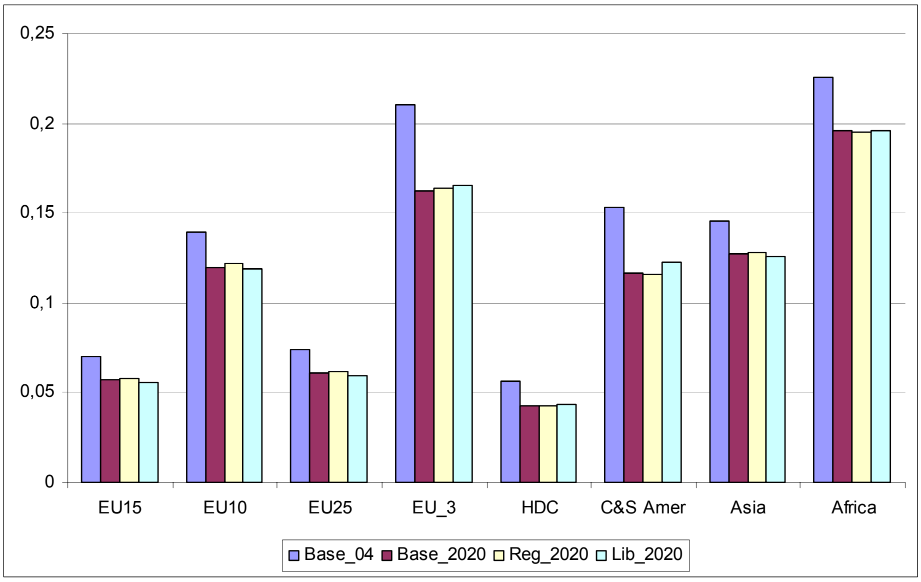

Figure A12.5 Share of agri-food complex in economy.

- The share of the agri-food complex (see Figure A12.5) and manufacturing industries (see Figure A12.6) in the economy keeps on falling in all scenarios for 2020 compared to 2005. This is one of the characteristics of the structural change process as an economy grows. The higher the welfare level in a country the more important services become and the lower the share of the agri-food complex and industries.
- Share of primary agriculture is about half the share of the agri-food complex
  - About 40% in EU-15 and other high income countries
  - 45% in EU-10,
  - 70% in EU applicant countries and developing countries

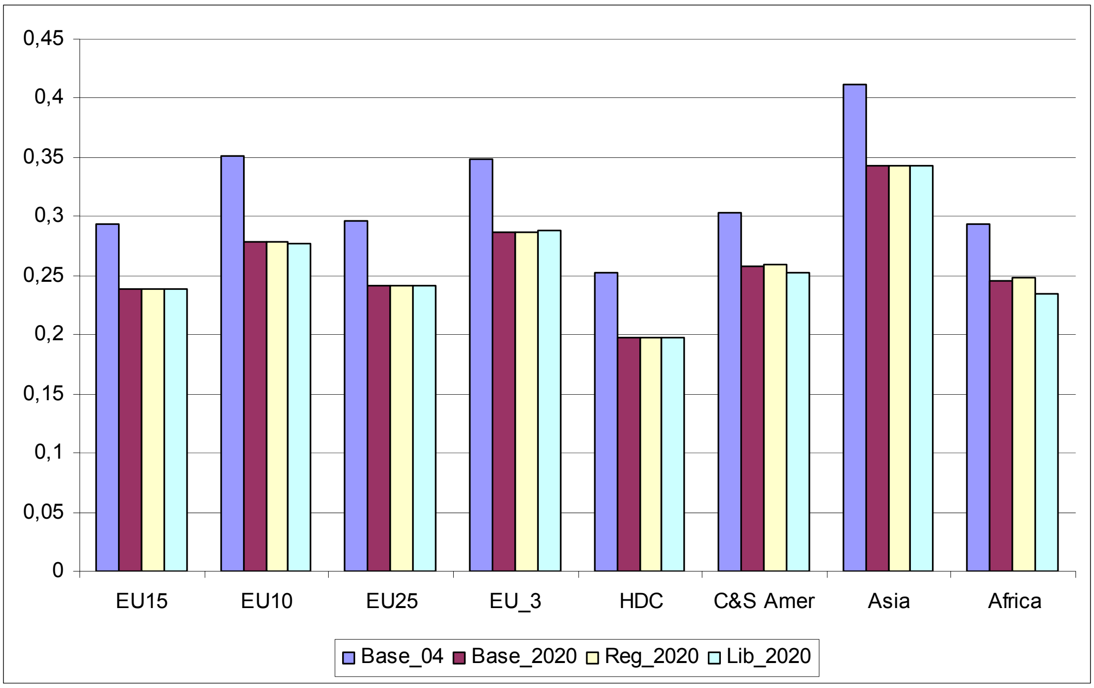

Figure A12.6 Share of manufacturing industries in economy.

- The historic trend continues in the sense that the shares of agri-food complex in economy keep on falling. On the one hand people spend relatively less money on food as their income gets higher (low income elasticity of demand), on the other hand productivity growth is higher in agriculture than in other sectors such as services. The latter effect causes agricultural prices to decline relatively to the general price index. People do not buy much more food if it gets cheaper (a low price elasticity of demand). All in all, the value share of agriculture will decline. The same is true in the manufacturing sector. However, for manufacturing commodities the income elasticity is higher than for agricultural commodities. The main reason for a decline in the manufacturing sector is the high growth of labour productivity in this sector.
- Process of structural change for the agro-complex is much higher in the EU-3 and EU-10 countries than in the EU-15. This implies that more labour will be released from the agri-food complex in these countries (given the assumption that in the longer run labour will earn equal wages in both the agricultural and non-agricultural sectors).
  - The share of the agri-food complex is much higher in the EU-10 than in the EU-15. It is still very high in the EU applicant countries and in developing countries. So in EU-10 and EU-3 agri-food is important.
  - The change in the agri-food share is highest in EU-10 and EU-3
- The policy impact seems limited as the differences between the regional focus and reinforced liberalisation scenarios with the baseline scenario are limited. In general the share of the agri-complex stays highest in the regional focus scenario. This is especially true for the EU applicant countries (EU-3) as they get preferential access to the other EU-25 countries, and this preferential access is not eroded by trade liberalisation. The opposite is true for Central and South America (e.g. Brazil), where the agri-complex share is lowest in the regional focus scenario because these countries cannot benefit from trade liberalisation.

General conclusion

- Process of structural change will continue with or without policy changes. Policies can temper or accelerate the process just a little bit.
- Structural change means both a declining output share for the agri-food complex as well as for the manufacturing industries.

- For the regional impact analyses, the current agri-food and manufacturing industry structure should be taken into account. Regions with a high share of these industries are potentially vulnerable for the structural change process, and therefore also for the effect of liberalisation that accelerates this process.

Trade

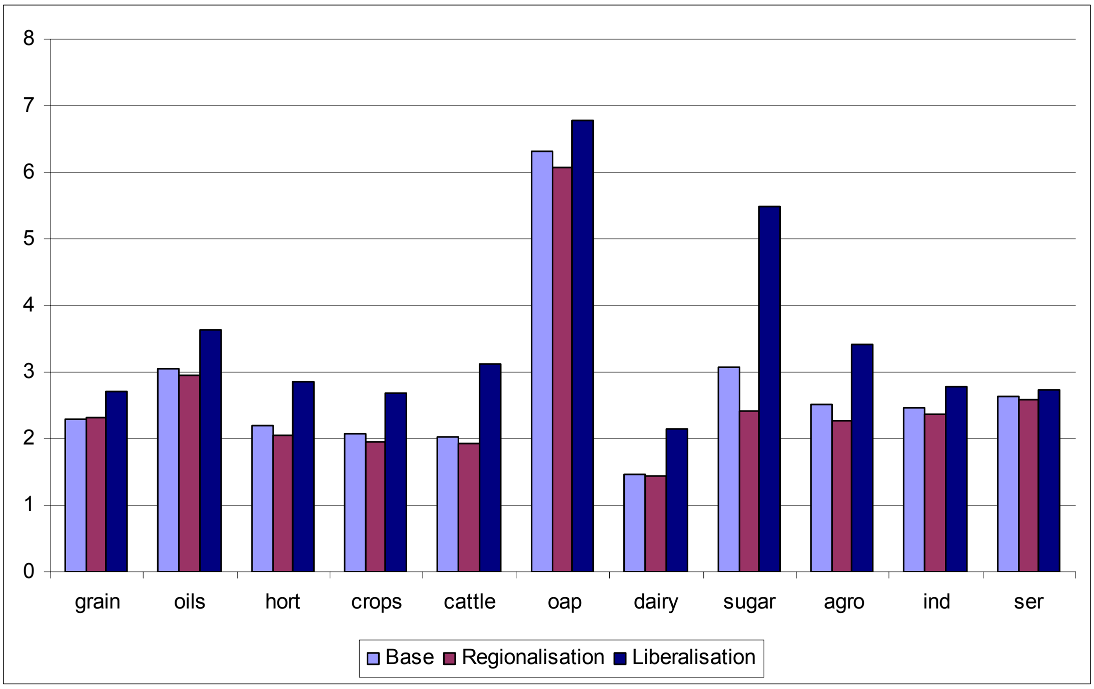

Figure A12.7 World trade growth, yearly growth rates, period 2005-2020.

World trade growth increases in all scenarios, especially in the liberalisation scenario.

- The difference in world trade growth between liberalisation scenario and the baseline and regional scenarios is striking. The higher growth in the liberalisation scenario is caused by the impact of multilateral liberalisation itself (see Figure A12.7).
- The growth in world trade is highest in oilseeds (oils), pork and poultry (oap) and processed food (agro).
- Impact for the manufacturing industries (ind) is not so high, as the current level of protection is not so high anymore due to liberalisation in the former WTO rounds (e.g. Uruguay Round)
- Impact for services (ser) is limited because we only included the reduction of tariffs and export subsidies, which are limited within services.

Production

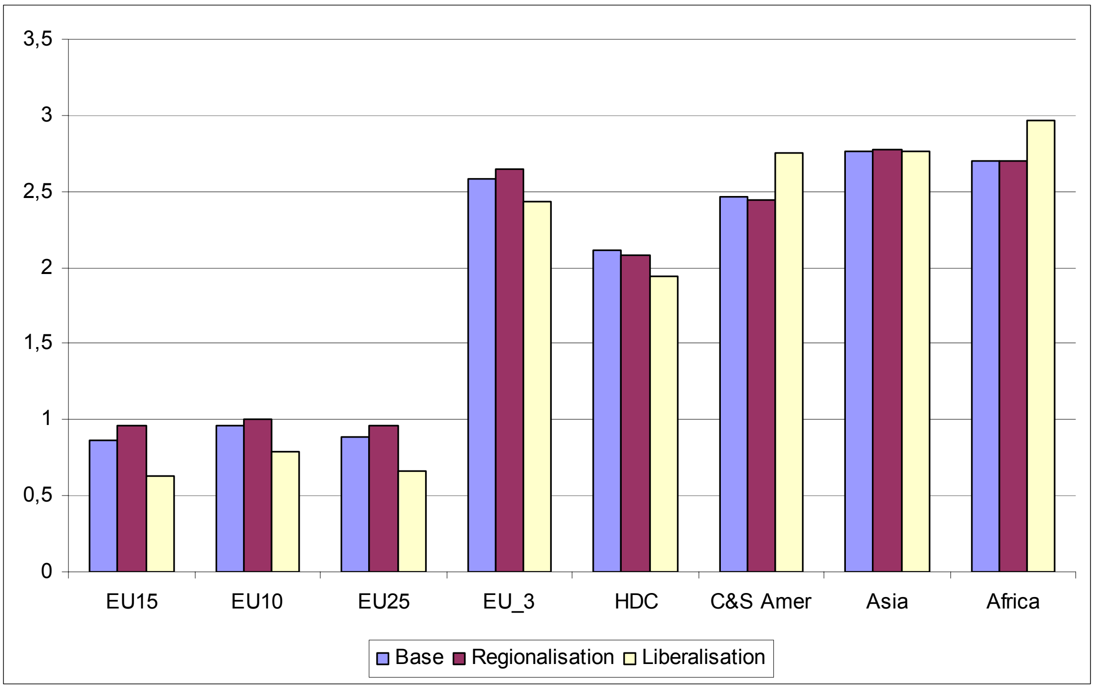

Figure A12.8 Growth of crop production 2005-2020, yearly growth rates.

- Growth of crop production is relatively low in the EU-25 countries in all scenarios. Growth is highest in the baseline scenario and lowest in the liberalisation scenario.
- Lowest growth for EU countries in liberalisation scenario is expected, although the impact of liberalisation on production is limited. Central and South America (e.g. Brazil) gain by liberalisation.
- Crop production growth is low in the EU relative to other countries/continents. Lower economic growth in combination with low income elasticity is important in this respect. In the liberalisation scenario sugar production in the EU will decline substantially.

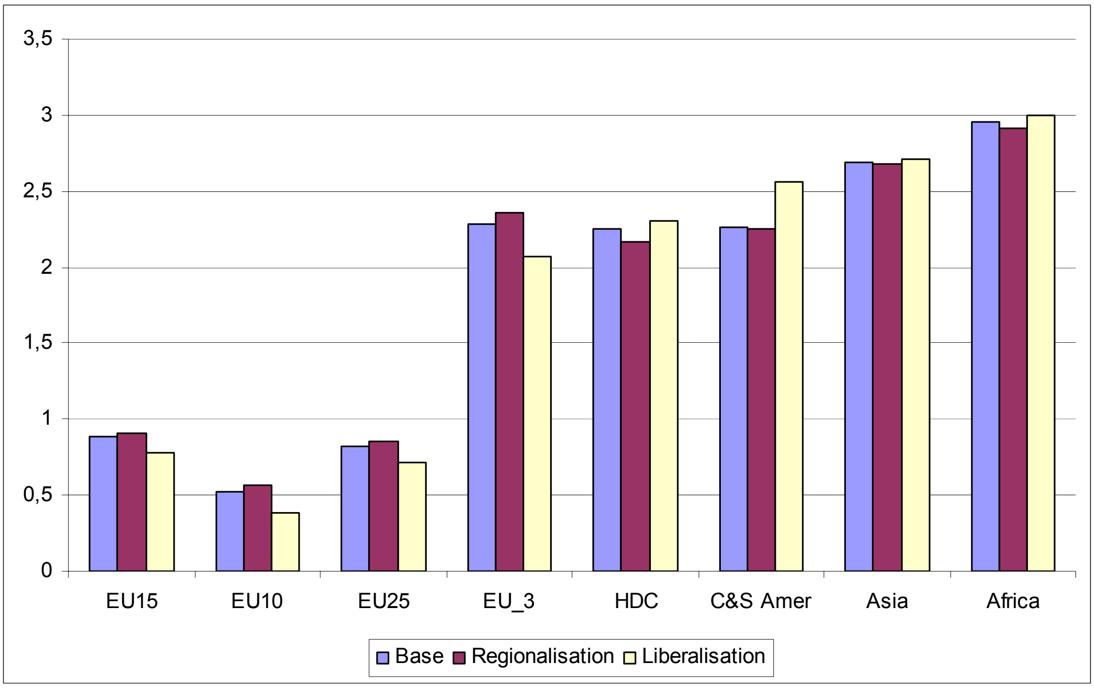

Figure A12.9 Growth of livestock production 2005-2020, yearly growth rates.

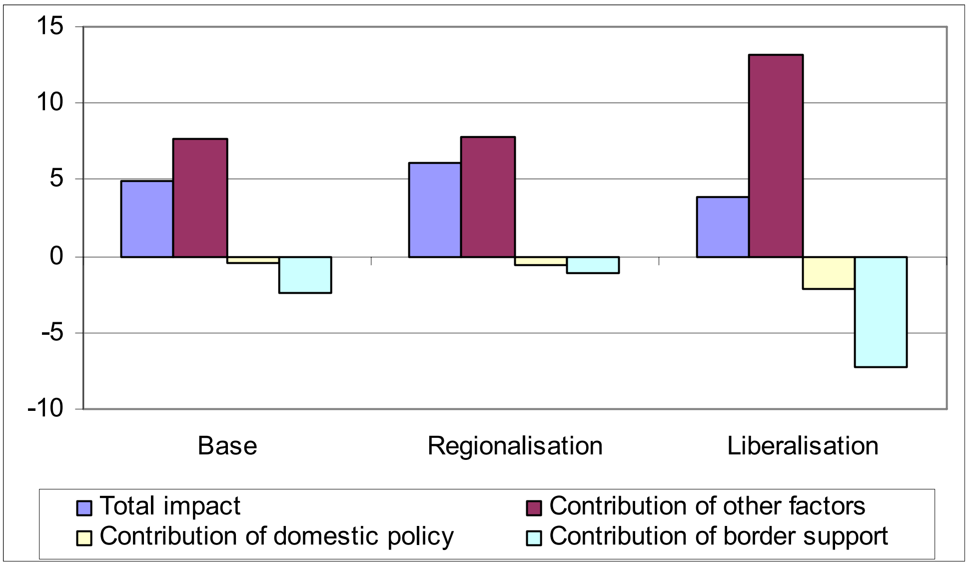

Figure A12.10 Decomposition of production growth of protected products for the EU-15, 2005-2020.

- An explanatory note. The outcome of a simulation is dependent on the changes in the assumptions of the exogenous variables and the model structure. With a decomposition method we trace the impact back to the changes in specific assumptions. In this case we are interested in the impact of changes in domestic and border support on production (grouping all the other assumptions in a third category). In Figure 10 production growth of protected products is 4.9% in the base scenario. The contribution of domestic policies is -0.5% and of border policies is -2.4%. The contribution of the changes in all other assumptions (e.g. macro shocks such as growth in technological change and endowments) is 7.7%.

- EU-15 production growth of products with protection (grains, oilseeds, sugar, beef and dairy) is low in the 2005-2020 period in all three scenarios. This is mainly due to the low income elasticity of demand.
- The production growth of protected products is highest in the regionalisation scenario and even negative in the liberalisation scenario.
- The contribution of changes in domestic support is negative in all scenarios. In the base and regionalisation scenario this is due to decoupling that partly redistributes payments from protected commodities to less protected commodities and enlargement impacts that provide income payments to the EU-10 and applicant countries and give them a competitive advantage. In the liberalisation scenario the impact is higher due the abolishment of all domestic support.
- The contribution of changes in border support (export subsidies and import tariffs) is negative in all three scenarios. The impact is limited in the regionalisation scenario for the EU-15 countries because the only change in border support is due to the MTR and sugar reform and the enlargement with applicant countries. In the base and liberalisation scenario the impact is more negative due to global liberalisation agreements. In the base the EU proposal is accepted and in the liberalisation scenario all border support is abolished. The latter has a severe negative impact for the production of protected commodities.
- The abolition of border support has a higher impact on production than the abolition of domestic or income support.

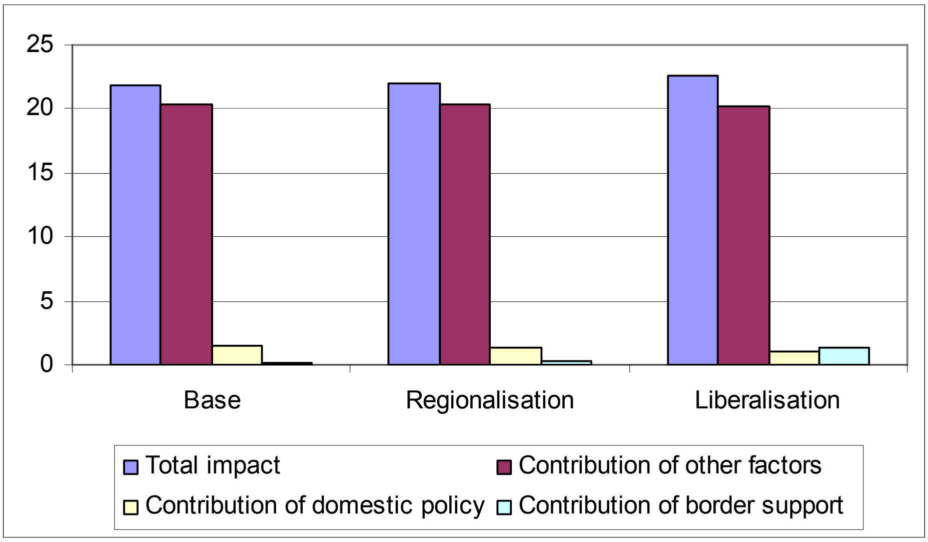

Figure A12.11 Decomposition of production growth of less protected products for the EU-15, 2005-2020.

- A comparison of Figure A12.10 and Figure A12.11 shows that production growth of protected products in the EU-15 countries is lower than for other agricultural products:

  1) This is because other agricultural products such as horticulture and pork and poultry have a higher income elasticity of demand.

  2) The impact of the policy changes is positive for other agricultural products. This policy impact is positive due to decoupling effects of domestic support (not only protected commodities but all agricultural products get support, except horticulture) and that the protected products become relatively less attractive under liberalisation relative to the less protected products.

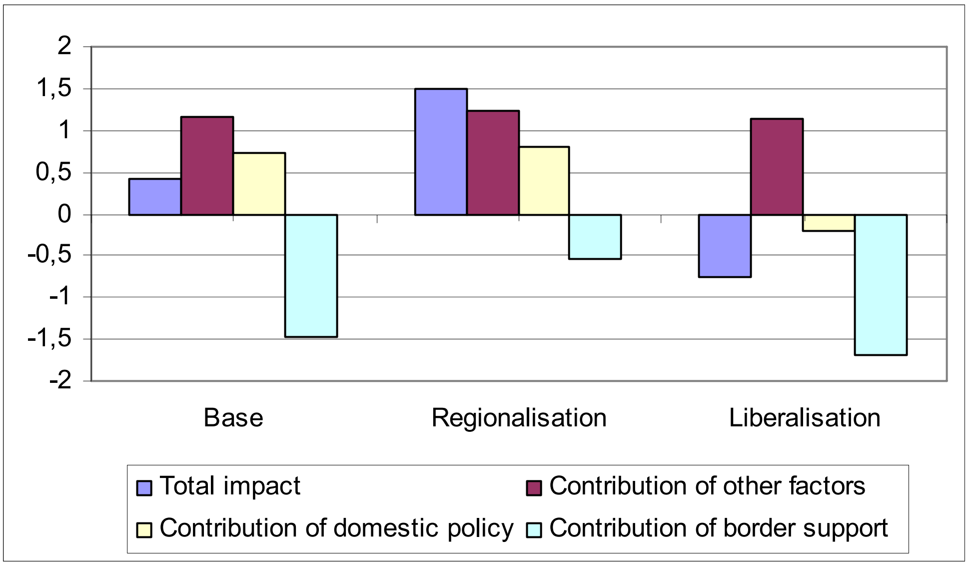

Figure A12.12 Decomposition of production growth of protected products for the EU-10, 2005-2020.

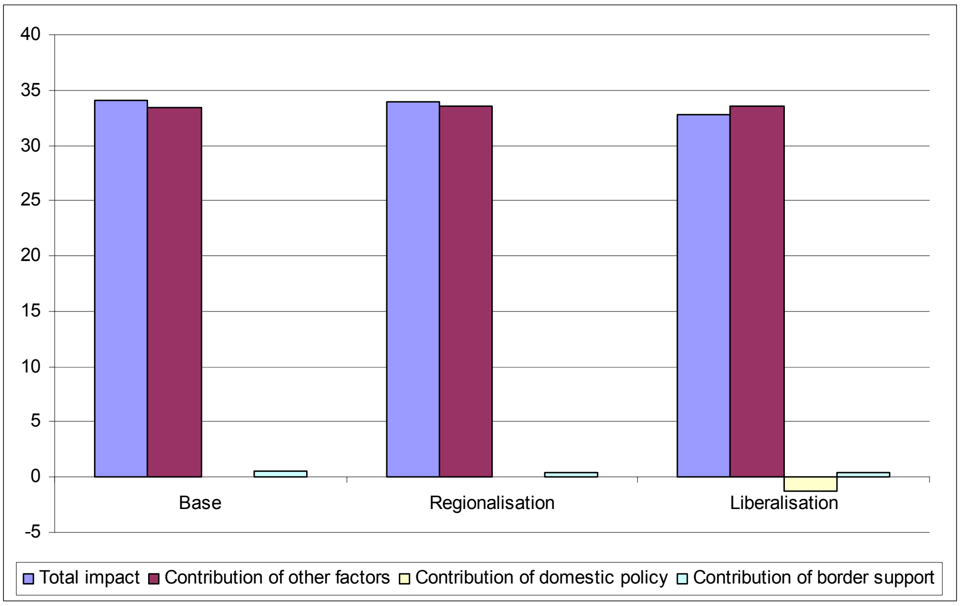

Figure A12.13 Decomposition of production growth of less protected products for the EU-10, 2005-2020.

Real farm income

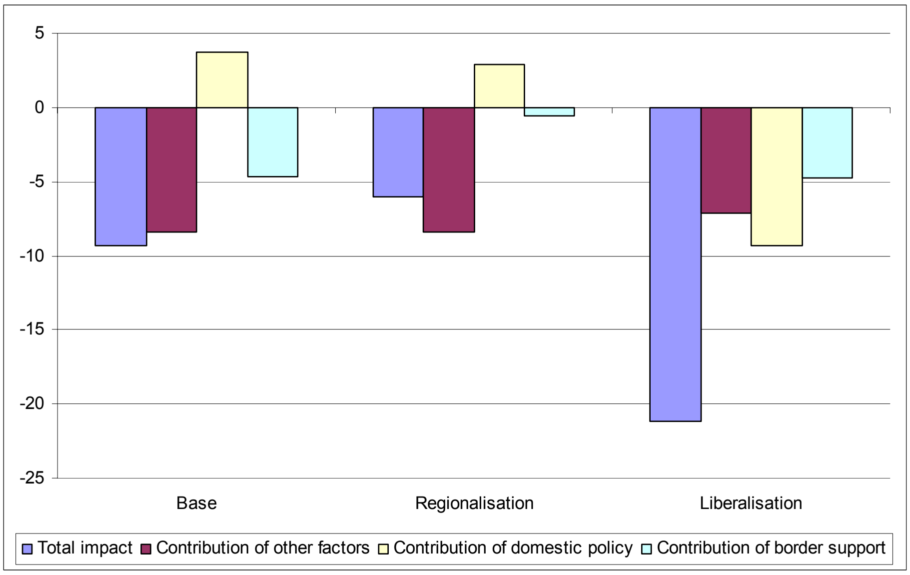

Figure A12.14 Real farm income growth for crop sectors in EU-15, 2005-2020.

- Income growth in the crops sectors is negative in the 2005-2020 period and it is determined by policy changes and other factors such as technical progress. The relatively high rate of technical progress in the crops sectors and the inelastic demand for crops cause a decline in real prices.
- Income is lowest in liberalisation scenario. This is mainly caused by the reduction of income support.
- In the base and regionalisation scenarios the impact of domestic support is limited because we do not reduce income support in these two scenarios (This is the case although modulation occurs in the baseline scenario as it is assumed that second pillar payments continue to be distributed within the agricultural sector). The positive impact is caused by the introduction of dairy and sugar payments and decoupling.
- A comparison of sections on production and income demonstrate that as expected the reduction of border support has a larger impact on production than domestic income support and with regard to income the impact of reducing domestic income support is larger.

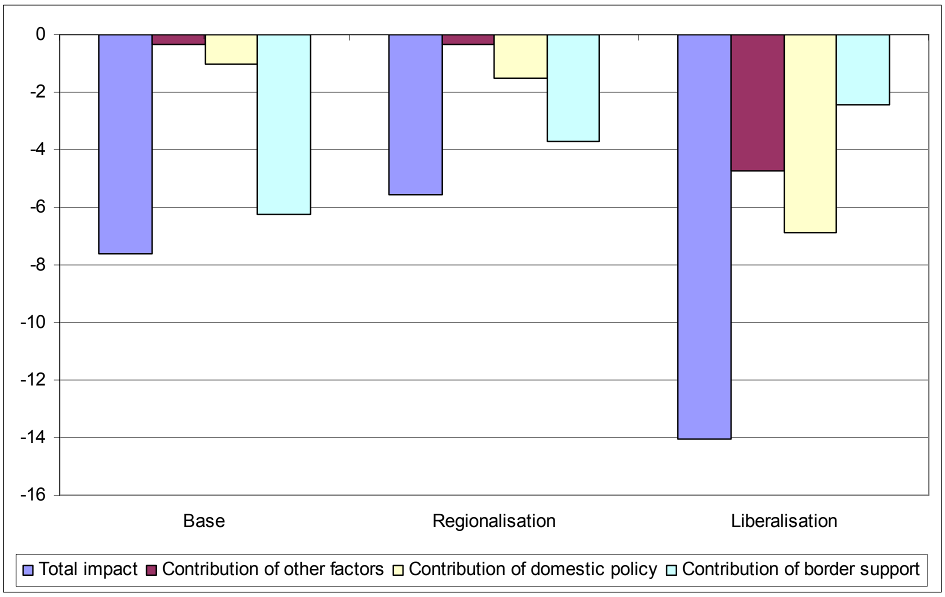

Figure A12.15 Real farm income growth for livestock sectors in EU-15, 2005-2020.

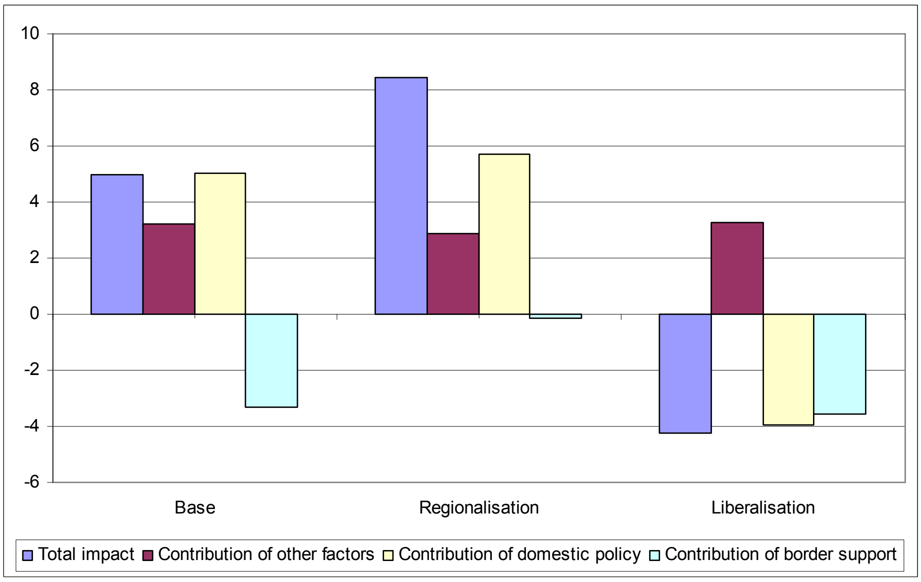

Figure A12.16 Real farm income growth for crop sectors in EU-10, 2005-2020.

- In the base and regionalisation scenarios the phasing in of the remaining 45% of the direct payments has a positive impact on farm income in the crop sectors (55% was already assigned in 2004 with the accession). This impact is negative in the liberalisation scenario as these income payments are abolished.

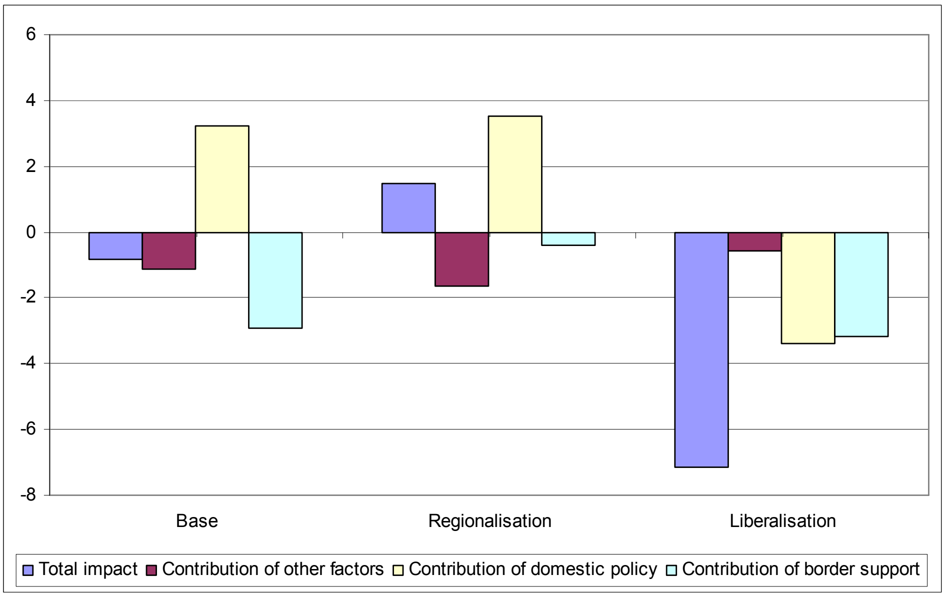

Figure A12.17 Real farm income growth for livestock sectors in EU-10, 2005-2020.

Employment effects

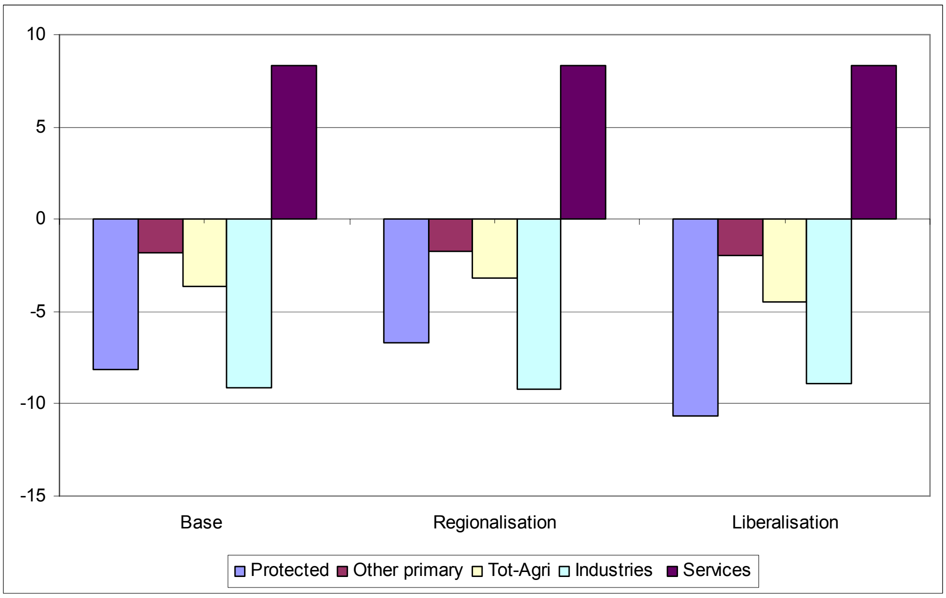

Figure A12.18 Sectoral employment growth in the EU-15, 2005-2020.

- Employment figures are in line with the structural change process.
- Employment in the agri-food and manufacturing industries decreases whereas it increases in the services sectors.
- The impact of liberalisation is negative on employment in especially the protected sectors.
- Figure A12.19 shows that employment effects in protected sectors are more pronounced in the EU-10 countries

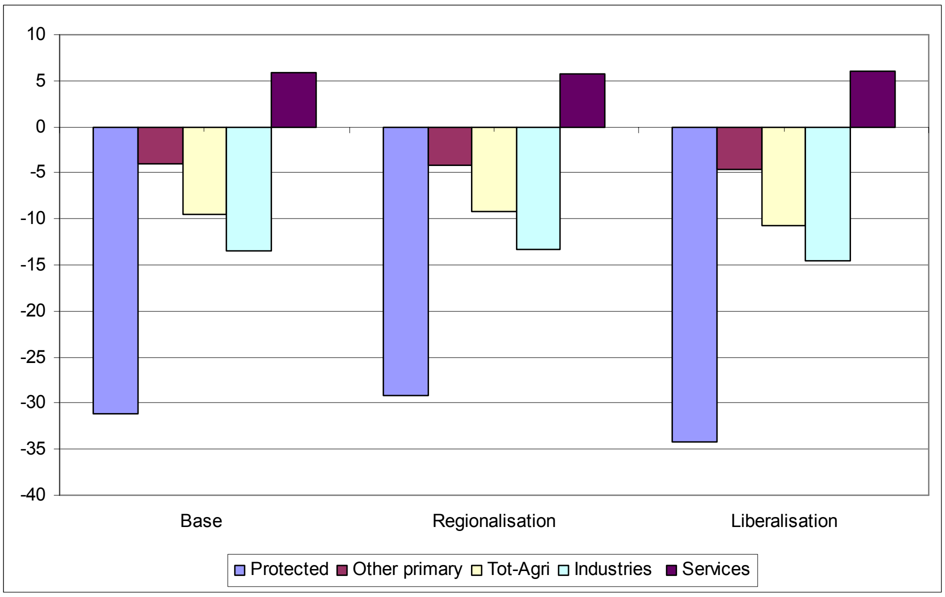

Figure A12.19 Sectoral employment growth in the EU-10, 2005-2020.

Factor prices

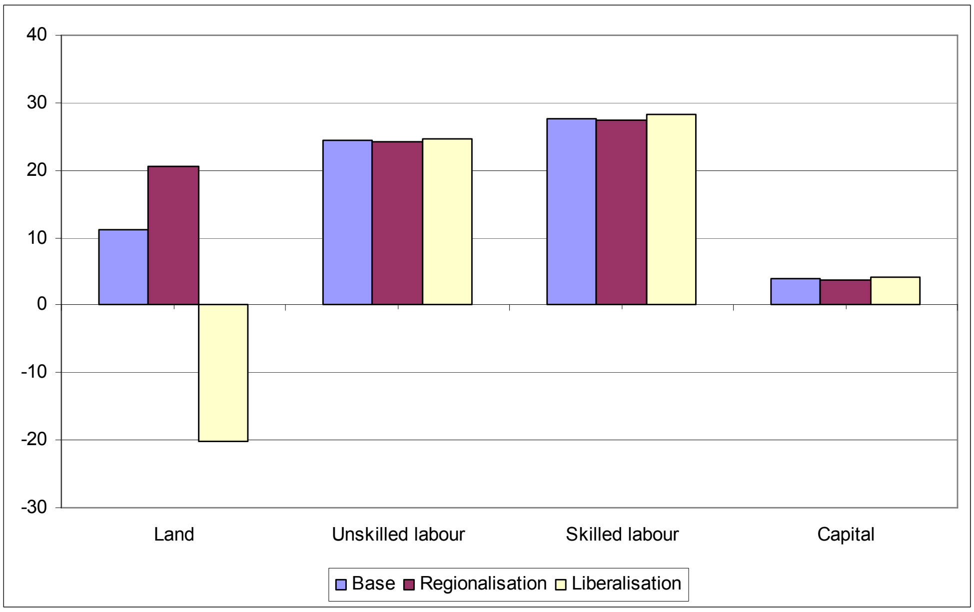

Figure A12.20 Development of real factor prices in the EU-15, 2005-2020.

- Highest increase in the wages relative to the price of other endowments for both EU-15 (Figure A12.20) and EU-10 (Figure A12.21). Increase in the wage rate of skilled labour is higher than the increase in the wage rate of unskilled labour. Increase in wages is a bit higher in liberalisation scenario and lower in the regionalisation scenario relative to the base scenario. Increase in wages is higher in EU-10 than EU-15 (catching up).
- The rental rate of capital rises not as quickly as the capital stock will be augmented with investments (it will not become as scarce as labour).
- Land price is very dependent on the policy scenario. The direct payments and profitability of agriculture accrue partly in the price of the fixed factor land. In the regionalisation scenario direct payments stay highest and agriculture is relatively to the other scenarios more

profitable: land prices are highest. In the liberalisation scenario land prices decline fast as all direct payments are abolished and profitability in agriculture is low.

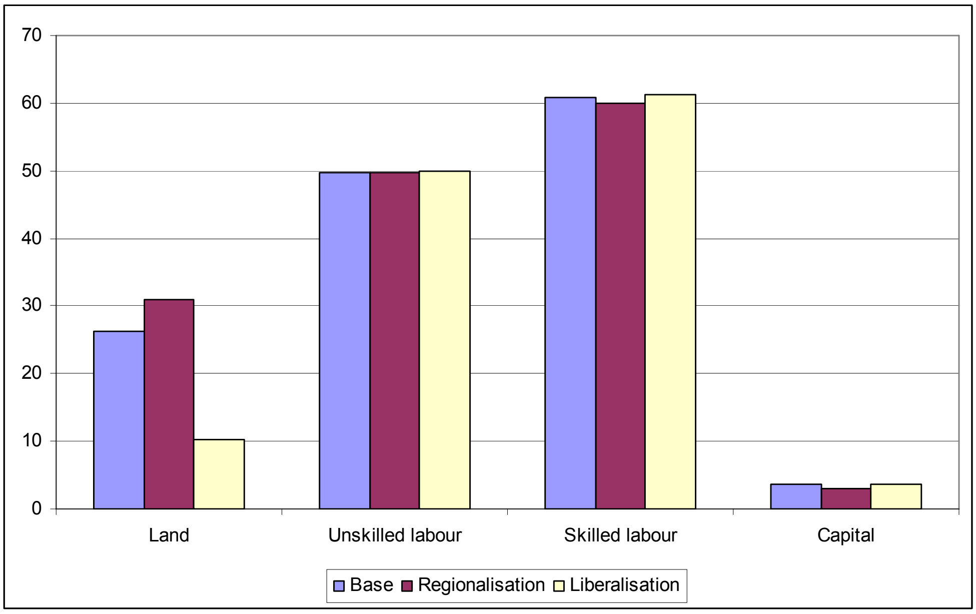

Figure A12.21 Development of real factor prices in the EU-10, 2005-2020.

An important observation is that wage differentials between agriculture and non-agriculture can be sustained in many countries through limited off-farm labour migration (De Janvry, 1991). Returns to assets invested in agriculture also tend to diverge from returns of investment in other activities. In the methodological part we incorporated this feature by a segmentation of the capital and labour factor markets between agriculture and non agriculture. The degree to which agricultural labour can be transformed in non agricultural labour is measured by the transformation elasticity. The elasticities of transformation in this study are calibrated to fit estimates of the elasticity of labour supply from OECD (2001). Figure 22 shows that these estimates imply that the wage differential between agricultural and non-agricultural sectors will continue to exist as wages in agricultural sectors increase less than these in non-agricultural sectors. This also implies that more labour stays in the agricultural sector than when employees in the agricultural sector earned the same wage as in other sectors.

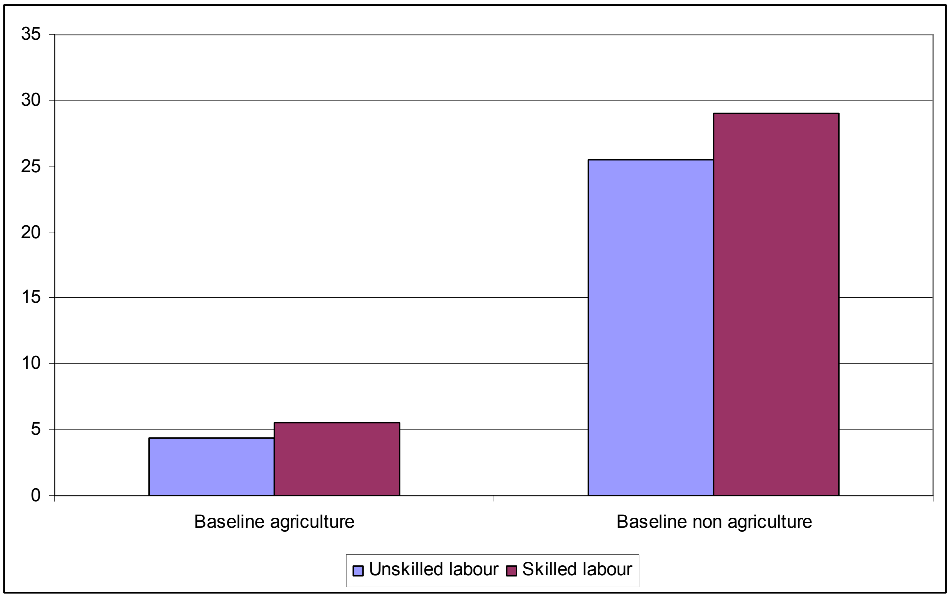

Figure A12.22 Development agricultural and non-agricultural wages in baseline scenario in EU-15 (market prices, 2005-202