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

Main report

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

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

Het betreft analyse- en assessment werk dat beoogt een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. Deze analyse- en assessment activiteiten hebben een looptijd van enkele maanden tot ca. een jaar, afhankelijk van de complexiteit en de urgentie van de beleidsvraag. Per onderwerp wordt een assessment team samengesteld bestaande uit de beste Nederlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Klanten zijn met name de NMP-departementen, met VROM in een coördinerende rol, maar tevens maatschappelijke groeperingen die een belangrijke rol spelen bij de besluitvorming over en uitvoering van het klimaatbeleid.
De verantwoordelijkheid voor de uitvoering berust bij een consortium bestaande uit MNP, RIVM, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het MNP is hoofdaannemer en draagt daarom de eindverantwoordelijkheid.

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

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

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

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Preface

This report was commissioned by the Programme Scientific Assessment and Policy Analysis Climate Change (WAB). The report was internally reviewed by the members of the Steering Committee of the Programme Scientific Assessment and Policy Analysis. The report was externally reviewed by Messrs Günther Fischer, Carsten Loose, Göran Berndes, Eric Ferguson and Jan Willem Storm van Leeuwen. Some of them gave extensive comments and suggestions, some of which could be included in the present final version of the document. The authors thank the reviewers for their contributions.

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Contents

List of Tables

List of Figures

Samenvatting

1. Omvang en aanpak

Deze studie omvat een uitgebreide analyse en beoordeling van beschikbare schattingen van het wereldwijde potentieel van biomassaproductie voor de energievoorziening. Daarbij ligt de nadruk op de verschillende factoren die het potentieel beïnvloeden, zoals voedselproductie, watergebruik, biodiversiteit, energievraag en de economie van de landbouw. Tevens worden enkele studies besproken die de broeikasgasbalans van bio-energie analyseren.

Na een uitgebreide inventarisatie van recente studies op de verschillende gebieden (voedselproductie, water, biodiversiteit, landbouweconomie en energievraag) analyseert deze studie de complexe verbindingen tussen deze factoren. Het integreren van de kennis over de effecten van de afzonderlijke factoren heeft effect op het potentieel van biomassaproductie en dit effect is berekend met de beschikbare modellen. De resultaten zijn vertaald in een overzicht van de onzekerheden in de huidige schattingen van biomassa potentieel, en dit geeft een samenvatting van de beschikbare kennis en van de kennislacunes. Deze analyse leidt tenslotte tot aanbevelingen voor beleid en onderzoek ten behoeve van een duurzaam gebruik van biomassa.

Sociale, juridische en institutionele aspecten van biomassa productie en gebruik — hoewel van groot politiek belang — zijn geen onderdeel van de studie geweest. Het opnemen van deze aspecten kan het beschikbare biomassa potentieel verminderen ten opzichte van de technische schattingen die in deze studie besproken zijn.

2. Achtergrond

Biomassa is de belangrijkste hernieuwbare energiebron, met een bijdrage van ongeveer 10% (46 EJ) aan de wereldwijde vraag naar primaire energie van 489 EJ (2005). Deze bijdrage is groter dan die van waterkracht (26 EJ) of kernenergie (26 EJ). Het leeuwendeel van het gebruik van biomassa (37 EJ) is niet-commercieel en heeft betrekking op het gebruik van houtskool, hout en mest voor koken en ruimteverwarming, meestal door de armere bevolking in ontwikkelingslanden. Modern gebruik van bio-energie (voor de industrie, elektriciteitsopwekking of voor transport) omvat al een significante bijdrage van 9 EJ, en dit aandeel groeit snel.

Dankzij de stijgende prijzen van fossiele brandstoffen is de concurrentiekracht van biomassa aanzienlijk verbeterd. Daarbij komt dat de ontwikkeling van CO_2 markten (emissiehandel) en de voortdurende leereffecten de economische drijfveren voor productie, gebruik en handel van biomassa voor energie hebben versterkt. De doelen en verwachtingen voor toepassing van bio-energie in het beleid van vele landen zijn ambitieus met percentages tot 20-30% van de totale energievraag in sommige landen voor 2020 - 2030. De verwachtingen voor energie uit biomassa zijn daarom groot. Vanwege de globalisering van bio-energie en de snelle stijging van de vraag worden biomassastromen van andere continenten nu in verschillende marktsegmenten gebruikt. Deze stromen omvatten plantaardige oliën zoals palmolie,, rietsuikerethanol, en pellets van reststromen uit de landbouw en bosbouw.

Het sterk toegenomen gebruik van biomassa voor energiedoeleinden en de potentiële groei ervan heeft een verhit debat op gang gebracht over de duurzaamheid van deze ontwikkelingen. Dit ook omdat biomassa productie nu in verband wordt gebracht met toegenomen competitie met productie van voedsel en veevoer, kappen van bossen, en veranderingen landgebruik. Naast deze concurrentie wordt ook de beoogde netto vermindering van broeikasgassen ten opzichte van energie uit fossiele brandstoffen in twijfel getrokken. Dit geldt vooral voor die gevallen waarin landgebruik voor biomassa geassocieerd wordt met het kappen van bestaande bossen, met de omzetting van veen- en turfgronden, en met de fossiele brandstoffen die nodig zijn voor machines, kunstmest en andere landbouw chemicaliën. Hoewel beschikbare studies een redelijk inzicht geven in het belang van de verschillende parameters, is de integratie tussen de verschillende gebieden nog steeds beperkt. Dit zorgt voor verwarring in het publieke en wetenschappelijke debat, met als resultaat lijnrecht tegengestelde meningen over de mogelijkheden van een duurzaam gebruik van biomassa voor energie. Deze studie heeft tot doel om dit probleem op te lossen door een brede analyse en beoordeling van de huidige kennis op het gebied van het biomassa potentieel.

3. Resultaten beoordeling beschikbare studies

De beoordeling richtte zich op de relatie tussen de biomassa potentieelschattingen en de beschikbaarheid en vraag naar water, de productie en vraag naar voedsel, de energievraag en de invloed op biodiversiteit en landbouweconomische parameters. Geen enkele van de acht recente potentieelstudies dekt alle aspecten, maar ieder heeft zijn sterke en zwakke punten, zoals te zien is in tabel S.1. De omvang van de studies, in termen van biomassa bronnen die meegenomen zijn, varieert nogal, evenals de aannames t.a.v. scenario's en methodes. Het gevolg is dat er grote verschillen zijn in de wereldwijde biomassa potentieelschattingen. Het hoogste biomassa potentieel van 1500 EJ voor 2050, berekend door Smeets et al. (2007), is gebaseerd op een intensieve en technisch hoogontwikkelde landbouw. Daartegenover staat de conclusie van Wolf et al. (2003) dat het biomassa potentieel in 2050 nul is, uitgaande van een pessimistisch scenario: hoge bevolkingsgroei, grote vraag naar voedsel en extensieve productiesystemen in de landbouw. In de studie van Hoogwijk et al. (2005) is uitgegaan van de productie van energiegewassen op verlaten en marginale gronden, en op ongebruikte graslanden. Hierbij worden de wereldwijde en regionale trends uit de IPCC SRES scenario's gebruikt met een toenemende landbouwkundige efficiency. Het resultaat is een potentieel van ongeveer 300 tot 650 EJ, afhankelijk van het scenario.

Tabel S.1: Overzicht en beoordeling van gekozen biomassa potentieel studies

Studie	**Onderwerp**	**Biomassa potentieel**	**Beoordeling**
Fischer et al., 2005	Beoordeling van eco-fysiologische biomassa opbrengsten	CEE, Noord en Centraal Azië; EG (populier, wilg, miscanthus); TP	*Sterk:* gedetailleerde differentiatie naar geschiktheid van land voor biomassa productie van specifieke gewassen op geografisch cel niveau (0.5 graad) *Zwak:* geen beoordeling van links naar voedsel, energie, economie, biodiversiteit en watervraag
Hoogwijk et al., 2005	Integrale beoordeling gebaseerd op SRES scenario's	Wereldwijd; EG (korte rotatie gewassen); TP	*Sterk:* integrale beoordeling voedsel, energie en vraag naar materialen, incl. scenario analyses; analyses van verschillende categorieën land (e.g. marginaal) *Zwak:* gewasopbrengsten niet gemodelleerd in detail voor verschillende soorten en management systemen
Hoogwijk et al., 2004	Kosten aanbodcurves gebaseerd op integrale beoordeling	Wereldwijd; EG (korte rotatie-gewassen); TP, EP	*Sterk:* stelt een wereldwijde kosten-aanbod curve op voor biomassa, gebaseerd op integrale beoordeling *Zwak:* verbinding tussen grondprijzen en energieprijzen niet meegenomen
Obersteiner et al., 2006	Biomassa aanbod van herbebossing en bosaanplant activiteiten	Wereldwijd; BP (incl. korte rotatie); EP	*Sterk:* modelleren van economisch potentieel door Netto Contante Waarde van landbouw en bosbouw te vergelijken op het niveau van rastercellen *Zwak:* opbrengsten van bosbouw productie niet afhankelijk van technologie niveau
Perlack et al., 2005	Biomassa aanbod studie gebaseerd op voorspellende studies uit landbouw en bosbouw	USA; EG, BP, BR, LR, SR, TR; TP	*Sterk:* gedetailleerde gebruik van mogelijke verbeteringen in landbouw productiesystemen (incl. genetische manipulatie) *Zwak:* geen integrale beoordeling, bijv: vraag naar voedsel en materialen niet meegenomen
Rokityanski et al., 2007	Analyse van mitigatie opties in landgebruik; methoden gelijk aan Obersteiner et al.	Wereldwijd; BP (incl. korte rotatie); EP	*Sterk:* beleidsanalyse van het stimuleren van landgebruik opties, inclusief CO2 prijzen; *Zwak:* landbouw grond niet meegenomen
Smeets et al., 2007	Bottom-up beoordeling van bio-energie potentiëlen	Wereldwijd; EG, BP, LR, BR, SR, TR; TP	*Sterk:* gedetailleerde bottom-up informatie over landbouw productiesystemen, inclusief veeteelt *Zwak:* opbrengstgegevens voor gewassen alleen regionaal gemodelleerd
Wolf et al., 2003	Bottom-up beoordeling van bio-energie potentiëlen, vooral voedselaanbod	Wereldwijd; EG; TP	*Sterk:* diverse scenario's van productiesystemen en vraag, met een brede range aan potentiëlen *Zwak:* opbrengsten van gewassen niet gespecificeerd voor diverse gewassen en typen land

Biomassa: EG – energiegewassen, BP: bosbouwproductie, BR: primaire bosbouw reststromen, LR: primaire landbouw reststromen, SR: secundaire reststromen, TR: tertiaire reststromen.
Potentiëlen: TP – technisch potentieel, EP – economisch potentieel

Deze recente studies geven een gedetailleerd en goed onderbouwd inzicht in het toekomstige potentieel van biomassa, maar geen van de studies omvat alle wezenlijke aspecten. Belangrijke zaken die onopgelost blijven en dus om aandacht vragen:
- De competitie om water met andere economische sectoren;
- Het toekomstige dieet van de mens en mogelijke alternatieve eiwitketens zijn maar zeer beperkt meegenomen;
- De invloed van verschillende dierlijke productie systemen moet in meer detail bestudeerd worden;
- De vraag naar houtproducten en andere biomaterialen is versimpeld en is niet gemodelleerd met een economische scenario analyse;
- De invloed van grootschalige biomassaproductie op de prijzen en dus de vraag naar land en voedsel is onvoldoende bestudeerd;
- De invloed van specifieke biodiversiteit doelstellingen op biomassa potentiëlen is niet in detail onderzocht.

Een van de interessante resultaten van deze evaluatie is dat, volgens de gehanteerde energiemodellen, de schattingen van de *vraag* naar bio-energie lager zijn dan de meeste *aanbod*schattingen, vanwege de concurrentie van bio-energie met andere energiebronnen. Dit speelt vooral bij elektriciteitsopwekking, omdat alternatieven zoals wind energie, fossiele bronnen met CO_2 afvang en opslag en kernenergie, attractiever blijken te zijn als de marginale biomassa kosten hoger zijn dan ca 3 US$/GJ. De schattingen van de vraag naar biomassa voor energiedoeleinden variëren tussen 50 en 250 EJ. Met andere woorden: we hebben waarschijnlijk minder biomassa nodig dan we theoretisch kunnen produceren.

De effecten van het telen van bio-energie gewassen op *biodiversiteit* worden gewoonlijk niet meegenomen in de verschillende wereldwijde potentieelstudies. Biodiversiteit wordt meestal beperkt tot de aanname dat de huidige beschermde natuurgebieden niet voor biomassa productie worden ingezet. In die zin wordt biodiversiteit wel meegenomen, maar op een zeer beperkt niveau. Vele andere publicaties en artikelen rapporteren over de effecten op biodiversiteit van de teelt van gewassen voor bioenergie productie, maar leiden tot geheel verschillende en soms tegengestelde resultaten. Dit wordt veroorzaakt door het gebruik van verschillende tijdschalen (korte of lange termijn), verschillende waarnemingsgebieden (lokaal, regionaal of wereldwijd), en door het hanteren van verschillende definities van biodiversiteit. Vaak wordt het gebruikte concept van biodiversiteit niet expliciet gedefinieerd. Het kan variëren van "natuurlijkheid" (b.v. de grootte en kwaliteit van natuurlijke leefomgevingen), tot "agro-biodiversiteit" (b.v. het aantal soorten planten en dieren, vooral vogels, dat van extensief management afhankelijk is).

Op de lokale schaal hangen de geconstateerde effecten meestal af van het vroegere landgebruik en het type bio-energie gewassen die worden geteeld. Als natuurgebieden gebruikt worden dan gaat de (natuurlijke) biodiversiteit vanzelfsprekend verloren door het andere landgebruik. Eerste generatie Europese landbouwgewassen doen het in dat opzicht op lokaal niveau slechter dan gemengde teeltsystemen.

Vanuit een meer wereldwijd en integraal gezichtspunt hangt het effect van het grootschalig telen van energiegewassen op biodiversiteit af van de balans tussen het op korte termijn (meestal) negatieve effect van de verandering van landgebruik en het op lange termijn positieve effect van verminderde klimaatverandering door alle ingezette klimaatmaatregelen. In de zgn. "safe-landing" scenario studie die uitgevoerd is voor de 2^{e} Global Biodiversity Outlook (gericht op 450ppm CO_2-equivalent in 2100), bleek deze balans negatief uit te vallen. Gegeven de onzekerheden in de uitkomst zou de balans echter ook kunnen omslaan.

Op het gebied van *water* gaven de studies grote verschillen te zien: in sommige gebieden geeft de goede beschikbaarheid van water alle ruimte voor het telen van energiegewassen, terwijl in andere gebieden de waterschaarste een serieuze belemmering vormt. Uit een vergelijking van de verschillende analyses blijkt dat de problemen op een hogere schaal worden geanalyseerd dan de geformuleerde oplossingen. De grote regionale variatie in klimaat en hydrologie vraagt om een gedetailleerde en locale analyse van de biofysische mogelijkheden van gewasproductie. Om de beschikbaarheid van water voor energiegewassen goed te beoordelen is de schaal van een stroomgebied het meest geschikt. Op deze schaal kan de wisselwerking tussen de beschikbaarheid en het gebruik van water - zowel bovenstrooms en benedenstrooms – worden gegarandeerd. De lokale situatie moet worden geanalyseerd om de mogelijkheden van energie productie te beoordelen. Tot op dit moment zijn nauwelijks studies op dit gedetailleerde niveau gedaan en wereldwijde cijfers kunnen een verkeerde indruk geven.

Klimaatverandering zal de patronen van regenval gaan veranderen, terwijl de verdamping toe zal nemen door hogere temperaturen. Het netto effect op waterbeschikbaarheid hiervan is niet eenvoudig te voorspellen, en er kunnen grote variaties optreden tussen verschillende gebieden in de wereld. In het bijzonder de halfdroge en droge gebieden zullen geconfronteerd worden met verminderde beschikbaarheid van water, en in veel rivierstroomgebieden zullen meer en meer verdrogingsproblemen optreden. In het algemeen zullen in halfdroge en droge gebieden de negatieve effecten van klimaatverandering zwaarder wegen dan de voordelen, en daarmee de beschikbaarheid van water en dus ook de irrigatiemogelijkheden in veel gebieden negatief beïnvloeden.

Voedsel productie en vraag hangen sterk af van toekomstige ontwikkelingen op het gebied landbouwtechnieken, bevolkingsgroei, economische ontwikkelingen en veranderingen in dieet en nieuwe eiwitketens,. Technisch is het mogelijk om genoeg voedsel te produceren voor 10 miljard mensen, maar om dit te realiseren binnen de wensen van duurzame ontwikkeling is een enorme uitdaging. De veronderstellingen over de vraag naar voedsel zoals die worden gemaakt in de SRES scenario's (zie bijvoorbeeld de biomassa potentieel studie van Hoogwijk et al. ,2005) bestrijken een range van mogelijke toekomstige ontwikkelingen die in overeenstemming zijn met de FAO voorspellingen. Deze zijn gebaseerd op aanbod (productie + import - export) per land en per product. Het zijn de best beschikbare data, maar ze blijven relatief weinig gedetailleerd en ruw en dat geldt dus ook voor de voorspellingen die erop gebaseerd zijn. De grootste kennislacune in de beschikbare modellen en data is waarschijnlijk de voorkeur van de consument. Studies naar veranderingen in dieet geven aan dat naast beschikbaarheid en prijs, ook status aspecten en culturele trends een belangrijke rol kunnen spelen.

Uitgevoerde *landbouw-economische studies* bestuderen effecten op uitsluitend landbouwgronden en nemen bossen niet mee. Niet alleen hout maar ook tweede generatie biobrandstoffen worden veelal niet meegenomen in de studies. De uitgevoerde studies illustreren wel de noodzaak om concurrentie en interacties tussen landbouwmarkten mee te nemen. De productie van (1e generatie) biobrandstoffen beïnvloedt de prijzen van voedsel en veevoer en deze effecten zijn onmisbaar om een realistisch beeld te schetsen van de beschikbare biomassa voor biobrandstoffen. Deze effecten zijn ook van belang om de "sociale duurzaamheid" van bio-energie te beoordelen, in het bijzonder de effecten op regionale inkomens en voedsel zekerheid. De sleutelparameters van de drijvende krachten achter landbouwproductie variëren nogal en zijn bovendien dynamisch. Huidige landbouweconomische modelstudies, zoals EU-RURALIS, beginnen nu dynamische aanbodcurves van biomassa voor energie en materialen mee te nemen die rekening houden met de concurrentie tussen voedselproductie en andere sectoren. De resultaten van deze landbouw-economische berekeningen tonen grote verschillen in toekomstige prijsontwikkelingen en de verhouding van deze ontwikkelingen met de toekomstige productie van biobrandstoffen moet nog verder worden geïnterpreteerd.

Het verminderen van de *emissies van broeikasgassen* is een belangrijke drijfveer voor het gebruik van biomassa voor energie en materialen. Veel studies hebben betrekking op de broeikasgasbalans van biomassa productie en gebruik, hoewel de vermindering van broeikasgassen niet expliciet wordt geanalyseerd in de bekeken potentieelstudies. De meeste biomassa ketens blijken netto emissievermindering op te leveren, maar de resultaten hangen af van het type gewas, de opbrengsten, waardering van bijproducten, het type energiedrager of materiaalgebruik, de veranderingen in landgebruik en het referentiesysteem van fossiele energiedragers. Biobrandstoffen voor transport van de 2e generatie worden meestal gunstiger beoordeeld dan die van de 1e generatie, omdat zij minder fossiele energie nodig hebben voor de productie van brandstof en de biomassa met een hoger rendement omgezet wordt.

4. Integratie van kennis uit de beoordeling van de studies

De beoordeling van de biomassa potentieel studies richtte zich op de verbanden tussen de invloed van (grootschalig) gebruik van biomassa voor energie en materialen op: voedselaanbod, watergebruik en biodiversiteit, rekening houdend met landbouweconomie, broeikasgasemissies en de modellering van de energievraag. Het bleek dat alle studies slechts een deel van de relevante parameters bekeken, en geen enkele studie het complete beeld kon geven. Een belangrijke reden is dat de betrekkingen tussen de parameters complex zijn, en daarom (nog) niet in detail kunnen worden weergegeven in een enkel model of studie. Figuur S.1 illustreert deze complexiteit door een aantal belangrijke relaties en veronderstellingen aan te geven.

Inzichten in de invloed van meer geïntegreerde overwegingen worden verkregen door gevoeligheidsanalyses uit te voeren met bestaande modellen. Het doel van deze analyses is niet om kwantitatieve antwoorden te geven, maar om de mogelijke invloed van de onzekerheden in bepaalde parameters in te kunnen schatten.

De analyse concentreerde zich op vijf hoofdonderwerpen:

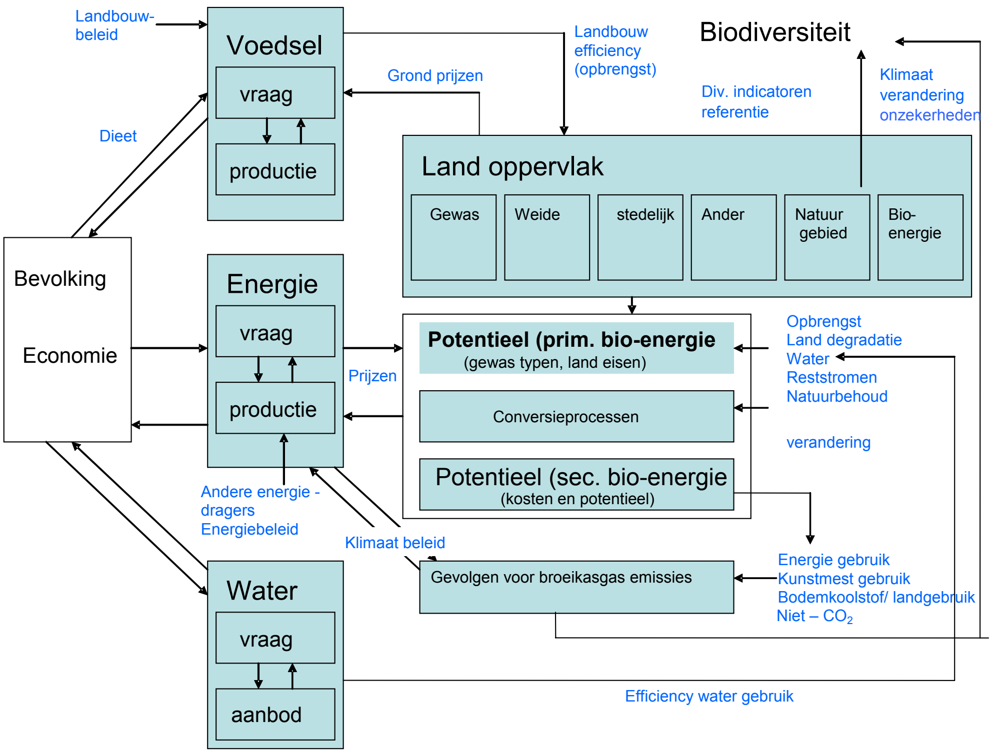
1. *De rol van het gebruik van bio-energie in energiemodellen*. Dit gebeurde vooral om na te gaan welke factoren het gebruik van biomassa voor energie kunnen beperken. Twee rekenexercities met het MARKAL model toonden aan dat biomassa vooral beperkt wordt door zijn marginale kosten, en niet door het aanbodpotentieel. TIMER exercities met verschillende koolstofprijzen lieten zien dat het biomassa potentieel stabiliseert op 130 EJ bij een belastingniveau boven US$100/ton koolstof. Biomassa als brandstof voor de elektriciteitssector zal goedkoper moeten zijn dan 3 US$/GJ om volledig te kunnen concurreren bij koolstofprijzen onder US$100/ton C.

2. *De gevoeligheid van bio-energie potentieelschattingen.* Dit betrof met name de onzekere ontwikkeling van landbouwtechnieken, landgebruik, waterschaarste, land degradatie en natuurreservaten. Een typisch voorbeeld met betrekking tot waterschaarste: het combineren van de bio-energie kaarten met de waterschaarste kaarten van het WaterGap model suggereert dat ongeveer 15% van het totale bio-energie potentieel zich bevindt in gebieden met ernstige watertekorten (en daarom niet beschikbaar zou kunnen zijn) en dat ongeveer 5% ligt in gebieden met een beperkte waterschaarste.

3. *Onzekerheden in de beoordeling van het verlies aan biodiversiteit als land voor bio-energie gebruikt wordt*. In het basis OECD scenario neemt biodiversiteit (MSA) af met 11% tussen 2000 en 2050. Ten behoeve van een ambitieus klimaatdoel van 450-ppm (CO_2 concentratie) wordt o.a. grootschalige bio-energie productie gerealiseerd met vooral houtige gewassen. Hiervoor wordt 1,8 miljoen km^2 verlaten landbouwgrond ingezet en wordt tevens 3 miljoen km^2 extensief gebruikte graslanden (die een semi-natuurlijk karakter hebben) gebruikt. Vergeleken met het basisscenario is dan de totale afname van de biodiversiteit 1% minder (dus 10% verlies van biodiversiteit in totaal).

4. *De economische verbanden tussen voedsel, veevoer en brandstof*. Voorbeeld: de EU biobrandstof richtlijn heeft een grote invloed op landbouwproductie en landgebruik, niet alleen in Europa maar ook in landen buiten Europa. Met name in Midden- en Zuid-Amerika neemt de landbouwproductie toe door de extra vraag naar biobrandstoffen in Europa. Om de ambitieuze Europese doelen te kunnen halen zal grootschalige productie van biobrandstoffen in Europa nodig zijn. Volgens modelresultaten van het landbouw-economische model EU-Ruralis zal met de Biobrandstof richtlijn uit 2003 bij een bijmengpercentage van 5,75% de vraag naar gewassen voor biobrandstoffen stijgen tot een waarde van 7,3 miljard USD (2001). Naar schatting 42% hiervan zal in Europa worden geproduceerd en 58% zal van import komen. Bij het Referentie scenario, waar bijmenging niet verplicht is, wordt de waarde van de gewassen voor biobrandstoffen veel kleiner: 2,5 miljard USD (2001).

5. *Onzekerheid in de invloed op de broeikasgasbalans*. Uit de onderzochte studies blijkt dat de meeste biobrandstofketens leiden tot een reductie van broeikasgassen vergeleken met hun fossiele tegenhangers, op basis van levenscyclusanalyses (LCA). De netto emissiereducties geven echter aanzienlijke verschillen te zien in de onderzochte studies, als gevolg van verschillen in gehanteerde methoden, ‚gebruikte invoerdata (zoals N_2O emissies bij bemesting en teelt), door verschillen in de prestaties van de biobrandstofketens en het wel of niet meenemen van bodememissies van CO_2 als direct gevolg van verandering van landgebruik.



Figuur S.1: Overzicht van de belangrijkste verbanden die relevant zijn voor het beoordelen van het potentieel aan bio-energie

5. Onzekerheden in de potentieel schattingen van biomassa

De integratie analyse heeft antwoorden gegeven op een aantal belangrijke vragen, maar heeft ook een aantal kennislacunes en onzekerheden aan het licht gebracht. De belangrijkste onzekerheden in deze studie zijn samengevat in tabel S.2 (kolom 1). Het oordeel over hun relatieve belang is met sterren aangeduid in kolom 2, terwijl hun invloed op het biomassa potentieel met de pijlen in kolom 3 is weergegeven. Tenslotte staat het resultaat van de integratiefase in de laatste kolom en wordt weergegeven als percentage van het geschatte biomassapotentieel van ongeveer 200 EJ/jaar uit het OECD basisscenario in IMAGE. Opgemerkt wordt dat de resultaten van de integratie analyse tot grootteordes leiden, maar niet gebaseerd zijn op een geïntegreerde model analyse.

*Tabel S.2: Overzicht van onzekerheden en hun invloed op het biomassa potentieel**

Onderwerp	**Belang**	**Invloed op biomassa potentieel in vergelijking met**	
Aanbod potentieel van biomassa		*Aanbod geschat in recente studies*	*OECD basis scenario in IMAGE*
Verbetering landbouw management	***	↑↓	↑ 40-65%
Keuze van gewassen	***	↓	↓ 5-60%
Vraag naar voedsel en dieetkeuze	***	↑↓	n.v.t.
Gebruik van gedegradeerde gronden	***	↑↓	↑ ca. 30-45%
Concurrentie voor water	***	↓	↓ 15-25%
Gebruik bijproducten land- of bosbouw	**	↑↓	n.v.t.
Uitbreiding van beschermde gebieden	**	↓	↓10-25%
Efficientie watergebruik	**	↑	n.v.t.
Klimaatverandering	**	↑↓	n.v.t.
Alternatieve eiwitketens	**	↑	n.v.t.
Vraag naar biomaterialen	*	↑↓	n.v.t.
Broeikasgasbalans van biomassaketens	*	↑↓	n.v.t.
Vraag potentieel van biomassa		*Vraag geschat in recente studies*	*biomassa vraag geschat in TIMER*
Bio-energie vraag versus aanbod	**	↑↓	↓ 80-85%
Kosten van biomassa aanbod	**	↑↓	n.v.t.
Leereffecten in energie-conversie	**	↑↓	n.v.t.
Markt mechanismen voedsel – voer - brandstof	**	↑↓	n.v.t.

Belang van het onderwerp op het geschatte biomassa potentieel: ***- groot, ** - gemiddeld, * – klein
Invloed op het biomassa potentieel: als dit onderwerp wordt meegenomen dan zal het potentieel uit de recente studies: ↑ - toenemen, ↓ - afnemen, ↑↓ - toenemen of afnemen.
n.v.t.: geen kwantitatieve analyse is uitgevoerd in deze studie
* Zie sectie 4.2 voor een meer gedetailleerde beschrijving van de resultaten in deze tabel

6. Conclusies: kennis en kennislacunes

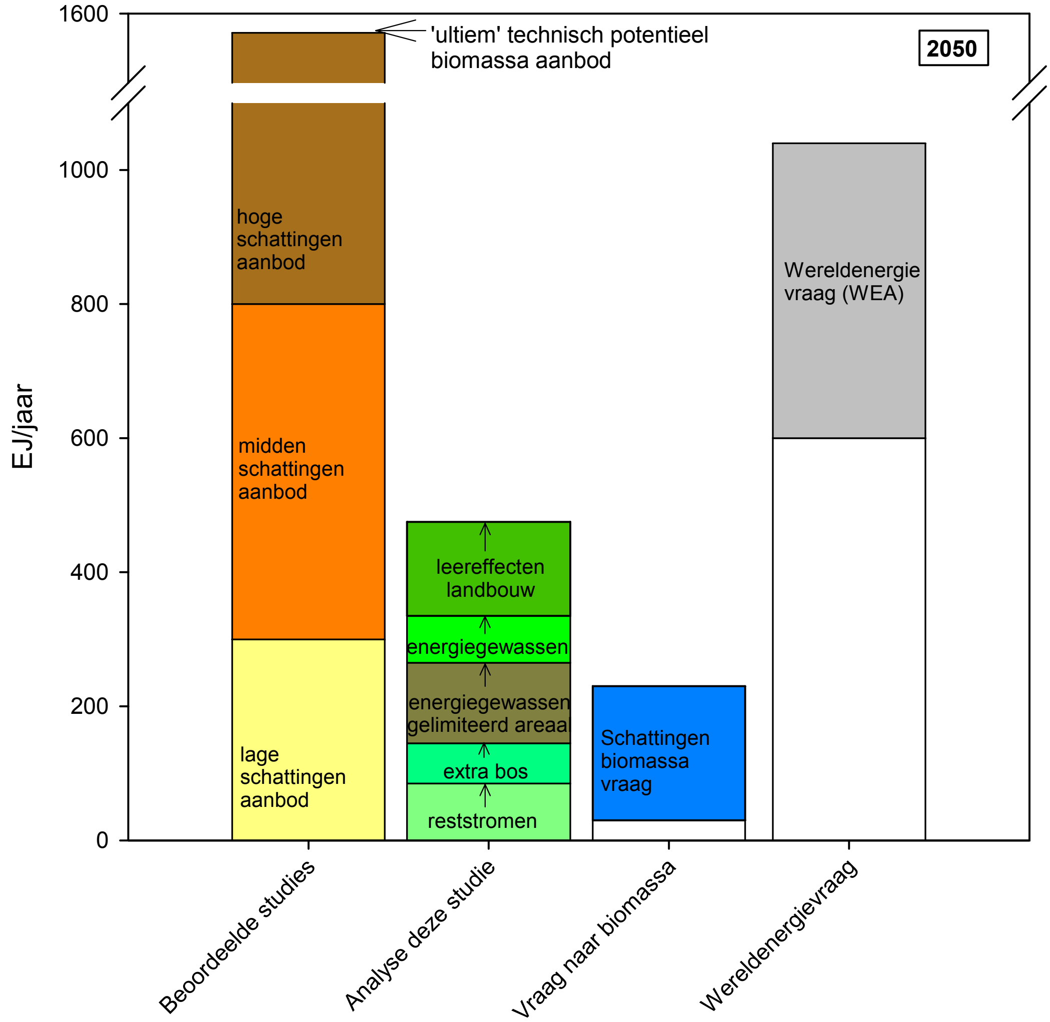
Een samenvatting van wat we wel en niet weten over biomassa potentiëlen is gegeven in hoofdstuk 4 van dit rapport. De samenvatting concentreert zich op tien sleutelvragen:

1. Is het potentieel voor productie van biomassa voor energie voldoende om in een aanzienlijk deel van de toekomstige energievraag te voorzien?
2. Wat is de drijvende kracht achter concurrerentie tussen gebruik van biomassa voor bio-energie en -materialen?
3. Wat zijn de belangrijkste bronnen van biomassa?
4. Welke rol kunnen gedegradeerde gebieden spelen in de productie van biomassa?
5. Wat bepaalt de opbrengsten van biomassa?
6. Is water een beperkende factor voor het realiseren van de biomassa potentiëlen?
7. Wat is de relatie tussen behoud van biodiversiteit en het gebruiken van biomassa voor bio-energie?
8. Wat is het effect van toepassing van biomassa voor energie op voedselprijzen?
9. Hoe kan de beschikbare biomassa het beste gebruikt worden?
10. Welke soorten analyses en studies zijn er nog nodig?

Het antwoord op de eerste vraag omvat een van de belangrijkste conclusies van deze studie, en daarom wordt deze hier behandeld.

Is het potentieel aan biomassa voldoende om in een aanzienlijk deel van de toekomstige energievraag te voorzien?

Het is zeer aannemelijk dat het wereldwijde potentieel aan biomassa voldoende is om biomassa een aanzienlijke rol te laten spelen in de wereldenergievoorziening. Op basis van de huidige kennis van de potentiële bijdrage van biomassa aan de wereldenergievoorziening wordt geschat dat het totale biomassa aanbod varieert tussen 100 EJ/jaar indien alleen reststromen worden gebruikt en een ultiem technisch potentieel van 1500 EJ/jaar. De gemiddelde en meer realistische schattingen bewegen zich tussen 300 en 800 EJ/jaar (eerste kolom in figuur S.1 hieronder). In deze studie zijn enkele gevoeligheidsanalyses uitgevoerd op de beschikbare resultaten, met betrekking tot water beschikbaarheid, bodemgesteldheid en het benutten van beschermde gebieden. De effecten hiervan zijn significant en hebben geleid tot een neerwaartse correctie van eerdere potentieelschattingen, tot een bandbreedte van ongeveer 200 tot 500 EJ/jaar (kolom 2 van figuur S.2)



Figuur S.2: Vergelijking tussen (1) de biomassa aanbodpotentiëlen in de beoordeelde studies, (2) de aanbodresultaten uit deze studie, (3) de vraag naar biomassa op basis van modelberekeningen in IMAGE en (4) de schattingen voor de wereldenergievraag in 2050 uit de World Energy Assessment (WEA)

Het potentieel aan aanbod van biomassa – rekening houdend met de verschillende onzekerheden zoals onderzocht in deze studie – bestaat uit drie hoofdcategorieën:

1. Reststromen van bos- en landbouw en organisch afval: zij omvatten een aanbod tussen 40 - 170 EJ/jaar, met een gemiddelde van ongeveer 100 EJ/jaar. Dit deel van de potentiële biomassa stroom is vrij zeker, hoewel concurrerende toepassingen van biomassa de netto beschikbaarheid naar de ondergrens van de range kunnen drukken. Dit laatste mechanisme moet nog beter onderzocht worden, bijvoorbeeld d.m.v. verbeterde modellen, die de economische aspecten van deze toepassingen meenemen.
2. Additionele bosbouw, d.w.z. naast de reststromen uit de bosbouw kan een extra hoeveelheid van ongeveer 60-100 EJ/jaar verkregen worden uit additionele bosgroei.
3. Biomassa geproduceerd via energiegewassen:
   a. Een schatting van de bijdrage van energiegewassen *op het mogelijk beschikbare overschot aan landbouw- en weidegronden* komt uit op 120 EJ/jaar, rekening houdend

met correcties voor waterschaarste, land degradatie en nieuwe claims op land voor natuurreservaten ("*energiegewassen gelimiteerd areaal* " in figuur S.2)

b. De potentiële additionele bijdrage van *gebieden met waterschaarste, marginale en gedegradeerde gronden* voor de productie van energiegewassen is 70 EJ/jaar. Dit omvat een groot areaal waar waterschaarste beperkingen oplegt en waar de degradatie van de grond ernstig is; beschermde gebieden worden uitgesloten van biomassa productie ("*energiegewassen*" in figuur S.2).
c. *Leereffecten in landbouwtechnieken* kunnen nog ongeveer 140 EJ/jaar toevoegen aan de bovengenoemde potentiëlen van energiegewassen.

De drie categorieën samen leiden tot een biomassa aanbod potentieel van ongeveer 500 EJ.

Energievraagmodellen, die het biomassa gebruik berekenen op grond van de kosten van concurrerende energieopties bij verschillende hoogtes van CO_2 belasting, komen voor het jaar 2050 uit op een vraag van 50 tot 250 EJ/jaar aan biomassa. Deze vraag naar biomassa voor energieproductie is lager dan het geraamde beschikbare aanbod. De totale wereldvraag naar primaire energie wordt voor 2050 geschat tussen 600 – 1040 EJ/jaar.

7. Aanbevelingen voor beleid

Gericht beleid kan de duurzame ontwikkeling van biomassa voor de energievoorziening ondersteunen door:

- Ontwikkeling en commercialisatie van sleuteltechnieken (bijv. 2^e generatie biobrandstoffen)
- Definiëren en toepassen van duurzaamheidcriteria voor de handel in biomassa en biobrandstoffen
- Investeringen in infrastructuur (landbouw, transport en omzetting van biomassa)
- Modernisatie van de landbouw en dit is vooral cruciaal in vele ontwikkelingslanden
- Natuurbehoud en bescherming van biodiversiteit, met goede definities en doelen voor duurzaam behoud en bescherming biodiversiteit.
- Regeneratie van gedegradeerde gronden (en het scheppen van de voorwaarden hiervoor) door inzet van energiegewassen.

Deze studie heeft bevestigd dat eenjarige voedselgewassen niet erg geschikt zijn als voornaamste bron voor biobrandstoffen, zowel wat betreft de omvang van hun potentiele productie als het kunnen voldoen aan een brede waaier van duurzaamheidcriteria. Overigens kunnen eenjarige voedselgewassen, onder bepaalde omstandigheden, toch een goed alternatief zijn, terwijl. meerjarige gewassen vaak andere perspectieven kunnen bieden. Meerjarige gewassen kunnen niet alleen op (additionele) landbouw- en weidegronden worden geteeld, maar ook op meer marginale en gedegradeerde gronden, hoewel ook deze gewassen daar een lagere opbrengst zullen hebben. Op dit moment is er nog maar beperkte (commerciële) ervaring met zulke systemen van meerjarige gewassen voor de energieproductie vooral op marginale en gedegradeerde gronden. Meer onderzoek en demonstratieprojecten zijn nodig om haalbaarheid aan te tonen en duurzame systemen te ontwikkelen die geschikt zijn voor een scala aan verschillende teeltcondities over de wereld. Dit vormt een belangrijke prioriteit in het landbouwbeleid inzake biobrandstoffen en bio-energie uit biomassa.

De grootste uitdaging in het realiseren van het biomassa productiepotentieel ligt vermoedelijk in het juiste ontwerp van strategieën voor beheer en implementatie van teeltsystemen en teeltmanagement. Zulke strategieën moeten de geleidelijke introductie van gewassen voor biomassaproductie in plattelandsgebieden mogelijk maken, waarbij tegelijkertijd de productiviteit van landbouw en veeteelt behouden wordt of zelfs toeneemt. Zoals uit deze studie blijkt is deze verhoging van de productiviteit een wezenlijk beleidselement, om te voorkomen dat er zogenaamde *competing claims* – conflicten over landgebruik - ontstaan of dat omvangrijke concurrentie ontstaat die leidt tot hogere voedselprijzen. Een succesvol beleid gericht op de ontwikkeling van het gebruik van bio-energie en biomassa productie zal dan ook verschillende doelen kennen. Het stellen van strikte eisen aan de vermindering van broeikasgassen zal bijvoorbeeld leiden tot andere keuzes van gewassen en land management vergeleken met een situatie waar er geen eisen worden gesteld aan vermindering van emissies broeikasgassen. Dit zelfde geldt ook voor duurzaam management van water, biodiversiteit en plattelandsontwikkeling. Het is duidelijk dat de keuze van de doelstellingen verschillend zal zijn

al naar gelang regionale situatie, mogelijkheden en belangen (vergelijk bijvoorbeeld het platteland in Afrika met West-Europa) en indien (regionale) afwegingen tussen verschillende doelstellingen zullen worden gemaakt. Het wordt hier aanbevolen om deze afwegingen expliciet en gebalanceerd te maken zodat ze heldere definities en grenzen bevatten die als uitgangspunt voor de ontwikkeling van biomassaproductie in een bepaalde regio kunnen worden gebruikt.
Internationaal en nationaal beleid en het identificeren en inzetten van de juiste stimulansen (subsidies of verplichtingen) zal – meer nog dan nu het geval is - juist op hierboven genoemde punten gericht moeten zijn om uiteindelijk succesvol te kunnen zijn.

Executive Summary

1. Scope and approach
This study provides a comprehensive assessment of global biomass potential estimates, focusing on the various factors affecting these potentials, such as food supplies, water use, biodiversity, energy demands and agro-economics. In addition, a number of studies analysing GHG balances of bioenergy are discussed.

After an extensive inventory of recent studies in the different areas (food, water, biodiversity, agro-economics and energy demand); this study integrates the complicated linkages between the various factors, quantifying the consequences of the linkages and knowledge found in the inventory within the limits of the presently available models. The results are translated into an overview of the uncertainties in biomass resource potential estimates and summarises the available knowledge and knowledge gaps. This analysis leads to policy relevant recommendations for sustainable biomass use in the future including R&D needs.

Social, legal and institutional aspects of biomass production and use — although of large political relevance — have not been part of this study. Including these aspects might reduce the available biomass potentials compared to technical estimates discussed in this study.

2. Background
Biomass is the most important renewable energy source, providing about 10% (46 EJ) of the annual global primary energy demand of 489 EJ (2005). This contribution is larger than those from hydropower (26 EJ) or nuclear power (26 EJ). A major part of this biomass use (37 EJ) is non-commercial and relates to charcoal, wood and manure used for cooking and space heating, generally by the poorer part of the population in developing countries. Modern bioenergy use (for industry, power generation, or transport fuels) is making already a significant contribution of 9 EJ, and this share is growing.

Due to rising prices for fossil fuels the competitiveness of biomass use has improved considerably over time. In addition, the development of CO_2 markets (emission trading), as well as ongoing learning effects have strengthened the economic drivers for increasing biomass production, use, and trade. Targets and expectations for bioenergy in many national policies are ambitious, reaching 20-30% of total energy demand in various countries. The expectations for bio-energy are therefore very high. Because of the globalisation of bio-energy and the steeply increased demand, biomass supplies from other continents are now used in various markets. This includes vegetal oils such as palm oil, rapeseed oil, bio-ethanol, and pellets from agricultural and forest residues.

The increased use and potential growth of biomass for energy has triggered a heated debate on the sustainability of those developments as biomass production is now also associated with increased competition with food and feed production, loss of forest cover and the like. Besides such competition, also the net reduction in GHG emissions is questioned in case land-use for biomass is associated with clearing (virgin) forest, with conversion of peat land, as well as with high fossil energy inputs for machinery, fertilisers and other agrochemicals. Although available studies give a reasonable insight in the importance of various parameters, the integration between different arenas is still limited. This causes confusion in public as well as scientific debate, with conflicting views on the possibilities for sustainable use of biomass as a result. This study aims to tackle this problem by providing a more comprehensive assessment of the current knowledge with respect to biomass resource potentials.

3. Results of the assessment activities
The assessment focused on the relation between estimated biomass potentials and the availability and demand of water, the production and demand of food, the demand for energy and the influence on biodiversity and economic mechanisms. None of eight recent potential studies assessed covers the whole range of issues, but they all have their strong and weak

points, as shown in table ES.1 on the next page. The scope of the studies, in terms of biomass resources included, varies as well as scenario and methodological assumptions. As a consequence, global biomass supply potentials vary widely. The highest biomass potential of 1500 EJ for 2050 determined by Smeets et al. (2007) is based upon an intensive, very high technologically developed agriculture. On the contrary, the zero biomass potential for 2050 calculated by Wolf et al. (2003) is caused by assuming a pessimistic scenario: high population growth, high food demands and extensive agricultural production systems. The study of Hoogwijk et al. (2005) refers to production of energy crops on abandoned, marginal and rest land assuming global and regional trends as described in the IPCC SRES scenarios, with increasing agricultural efficiency over time, leading to a potential of about 650 EJ.

Table ES.1: 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, miscanthus); 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 modeled
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

These recent biomass potential studies give detailed and well-founded insights into future biomass potentials, but none of the studies does include all critical aspects. Important issues that remain unresolved are:
- The competition for water with other economic sectors,
- Human diets and alternative protein chains have been included to a limited extent only
- The impacts of different animal production systems need to be studied in more detail
- The demand for wood products and other bio-materials has been simplified and has not been modelled based on economic scenario analysis.
- The impact of large-scale biomass production on the prices and subsequently on the 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.

One of the interesting results of the assessment is that the bioenergy *demand* estimates, according to energy demand models, are generally lower than most supply estimates, mainly because of the competition of bioenergy with other energy sources. This may in particular be true for power generation, because alternatives to reduce greenhouse gas emissions such as wind energy, fossils with Carbon Capture & Storage and nuclear energy, are more attractive when the marginal biomass costs exceed ca 3 US$/GJ. For the year 2050, the demand range of biomass is estimated to be between 50 and 250 EJ. In other words: we probably will need less biomass than we can theoretically produce.

The *biodiversity* effects of growing bio-energy crops are usually not taken into account in the different global potential studies. Biodiversity is typically treated by assuming that present nature conservation areas are excluded from biomass production. As such, the estimated biomass potentials take biodiversity into account, but at a limited base level only. Many other diverse research papers do report on actual biodiversity effects of bio-energy production (or comparable crops), but show different and sometimes opposite results. This is caused by using different time horizons (short or long term), different scales of observation (local, regional or global), and the different biodiversity definitions used. Often, the used biodiversity concept is not explicitly defined. It can vary from “naturalness” (e.g. the extent of natural habitats), to “agro-biodiversity” (e.g. number of crop species).

At the local scale, the noted effects mostly depend on the former land-use and the type of bio-energy crops that are grown. When natural areas are used, (natural) biodiversity is obviously lost through land conversion. First generation European agricultural crops do worse at the local level than mixed cropping systems, second generation perennials and woody crops.

In a more global and integral view, the effect of large scale energy crop cultivation on biodiversity depends on the balance between the short-term (mostly) negative effect of land-use change and the long-term positive effect of reduced future climate change. In a safe-landing scenario study performed for the 2nd Global Biodiversity Outlook (targeted at 450ppm CO_2-eq by 2100), this balance was negative. However, in determining the sign of this balance, uncertainties should be taken into account.

With regard to *water* the studies showed large differences: in some regions abundant water availability provides ample opportunities for energy crop production, while water scarcity in other regions is seriously restricting any opportunity for energy crops. 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 detailed and local analysis of the biophysical possibilities for crop production. To determine water availability for energy crop production a basin scale seems most appropriate in order to assure that the interaction between upstream and downstream water availability and use is taken care of. The local situation should be analysed to assess the scope for energy production. However, to date, studies at this resolution have only been done incidentally, and global figures give a misleading picture.

Climate change is likely to change rainfall patterns while water transpiration and evaporation will be enhanced by increasing temperatures. The net effect of this is not easy to predict, large variations can be expected among different regions of the world. Especially semi-arid and arid areas are expected to be confronted with reduced water availability and problems in many river basins may be expected to increase. Generally, negative effects of climate change will outweigh the benefits for freshwater systems, thereby adversely influencing water availability in many regions and hence irrigation potentials.

Food production and demand strongly depend on future development with regard to agricultural technology, novel protein chains as well as population growth, economic developments and dietary changes. While technologically speaking producing enough food for even 10 billion people seems feasible, doing so without compromising sustainability will be a formidable challenge. The assumptions on food demand that have been made within the SRES scenarios used for example in the biomass potential study of Hoogwijk et al. (2005) cover a broad range of possible future developments that are in line with current FAO projections. These are based on supply (production + imports - exports) per country, per commodity. They are the best available, but the descriptive data is crude and so are the projections based on them. The largest knowledge gap in the available models and data is probably in consumer preferences. Studies of diet change show that in addition to availability and price, status aspects and cultural trends play an important role.

The *agro-economic studies* that have been carried out often deal with agricultural land and do not take into account forestry land. They also do not deal with second generation biofuels. The studies carried out illustrate the necessity of including competition and interactions between agricultural markets. The production of biofuels affects prices of feed and food. Those effects have to be taken into account in order to present a realistic picture of available biomass for biofuel. These effects are also relevant to assess the social sustainability of bio-energy, especially the effects on regional incomes and food security. The key-parameters for the driving forces behind agro-production vary and are *dynamic*. Currently, agro-economic modelling studies as EU-RURALIS start to deal with dynamic supply curves of biomass for energy and materials taking the competition with food production and other sectors into account. The result of this agro-economic modelling exercises show large variations in terms of price dynamics and still need to be interpreted in relation to future biofuel production.

Reducing *GHG emissions* is a major driver for using biomass for energy and materials. Many studies deal with GHG balances of biomass production and uses, even though GHG emission reduction is not explicitly analyzed in the biomass potential studies reviewed. Most biomass chains turn out to reduce net GHG emission, but the results vary depending on the type of crop, the crop yields, the type of energy or material use, the land use changes involved and the fossil energy reference system. In general, second generation biofuels are more favourable than first generation biofuels as they tend to require lower energy inputs for biomass production and have a higher efficiency of biomass conversion.

4. Integration of knowledge from the assessment

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

Insights into the impacts of more integrated considerations are given by performing some sensitivity analysis using existing models. The aim of these analyses is not to provide quantitative answers, but instead to assess the possible impacts of some key uncertainties.

The analysis concentrated on five main issues:

1. The role of bio-energy use in energy models, in particular to identify which factors limit the penetration of bio-energy. The result of two MARKAL runs showed that biomass is mostly limited by its marginal cost, not by its supply potential. TIMER runs with different taxation levels showed that biomass stabilizes at 130 EJ at taxation levels of above US$100/tonne carbon. Biomass feedstock for the power sector should have costs below 3 US$/GJ to be fully competitive at carbon prices below US$100/tonne C.

2. The sensitivity of bio-energy potential estimates to issues such as uncertain development of agriculture technologies, land use, water scarcity, land degradation and nature reserves. A typical example for water scarcity: overlaying the bio-energy map with the water scarcity maps of the WaterGap model suggests that about 15% of the total potential for bio-energy is in severe water scarce areas (and might therefore be excluded) and another 5% is in areas with modest water scarcity.

3. Key uncertainties in assessing biodiversity losses as a result of land conversion for bio-energy. In the baseline OECD scenario biodiversity (MSA) declines by 11% between 2000 and 2050. For an ambitious 450-ppm option for climate change mitigation, large scale bio-energy production is implemented with mainly woody biofuels. For this, 1.8 million km^2 of abandoned agricultural land is used, and a further 3 million km^2 of extensively used grasslands (considered having a semi-natural character) are converted. Compared to the baseline, the total biodiversity decline in the option is 1% less (relative difference of 10%).

4. The economic links between food, feed and fuel. Example: the EU-biofuel directive has a strong impact on the agricultural production and land use not only in Europe but also to countries outside Europe. Especially in Central and South America the agricultural production increases due to the additional demand for biofuel crops in Europe. To meet the ambitious future targets large scale production of biofuel crops in Europe will be necessary. In the Biofuel-Directive scenario the demand for biofuel crops used in the petrol sector will be 7.3 billion USD (in 2001 values) under the minimum blending of 5.75%. Around 42% of these inputs will be produced domestically in Europe and 58% of biofuel crops used in the petrol sector will come from imports. Under the Reference scenario where mandatory blending is not enforced the use of biofuel crops is much lower: 2.5 billion USD.

5. Key results and uncertainties in impacts on greenhouse gas balances. The main results of the reviews is that in most biofuel chains turn out to reduce net GHG emission compared to their fossil counter-parts on a life-cycle basis with few exception found in the studies reviewed. The net results on GHG emission reduction in the analyzed studies however, vary widely due to variations in methods and input data (e.g. rate of N_2O emissions) and due to differences in the performance of different biofuel chains.

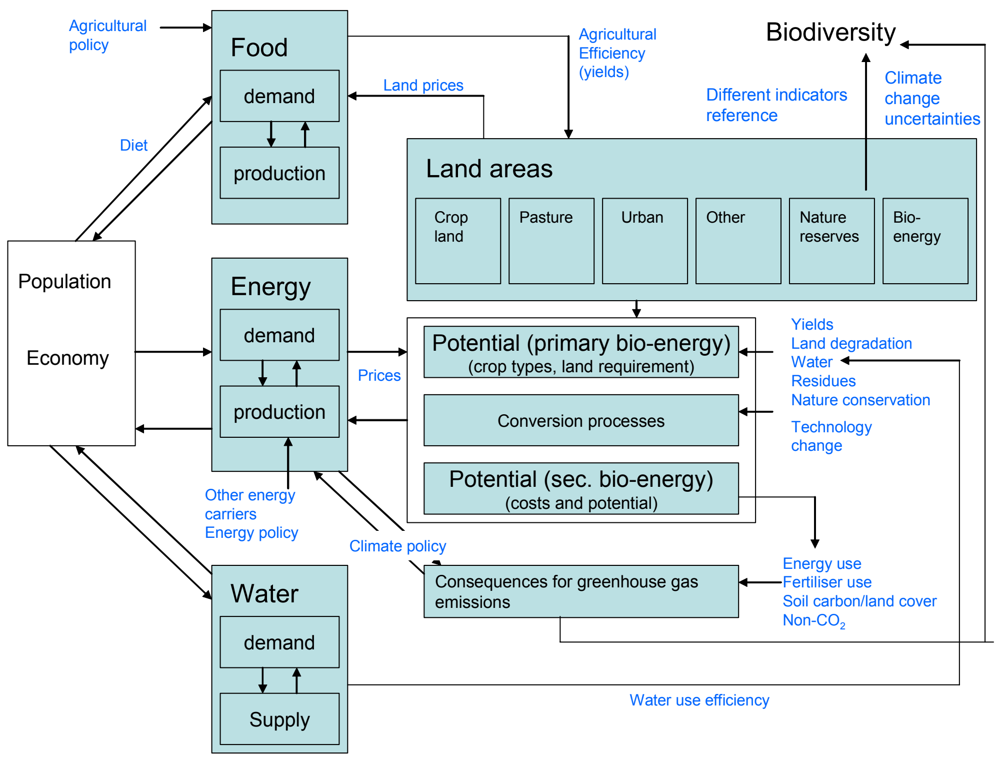


Figure ES.1 Overview of key relationships relevant to assess potential bio-energy supply.

5. Uncertainties in biomass potential estimates

The integration analysis provided answers to a few key questions, but also showed knowledge gaps and uncertainties. The key uncertainties identified in this study are summarized in table ES.2 below (column 1). They are evaluated according to their importance (column 2) and the impact on biomass potentials as estimated in the literature reviewed is presented (column 3). In addition also the results of the integration phase are presented (column 4). Percentages of supply refer to the OECD baseline scenario in IMAGE that estimates biomass potentials of about 200 EJ/yr. It should be noted that the results of the integration analysis provide an order of magnitude but are not based on an integrated modelling analysis.

Table ES.2 Overview of uncertainties and their impact on biomass resource potentials[*]

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

Importance of the issues on the range of estimated biomass potentials: ***- large, ** - medium, * – small
Impact on biomass potentials: potentials as estimated in recent studies would: ↑ - increase, ↓ - decrease, ↑↓ increase or decrease – if this aspect would be taken into account.
N/a: no quantitative analysis has been carried out in this study
[*] See Section 4.2 for a more detailed description of underlying results of this Table

6. Conclusions: knowledge and knowledge gaps

A summary of what we know and what we don't know concerning biomass potentials is presented in Chapter 4 of this report. This is shaped around ten key questions:

11. Are biomass potentials sufficient to supply a large part of future energy demands?
12. What drives the economic competitive use of bioenergy and materials?
13. What are the main sources of biomass?
14. What role might degraded lands play in biomass production?
15. What determines biomass yields?
16. Is water a limiting factor for biomass potentials?
17. What is the relation between biodiversity conservation and using bioenergy?
18. What is the effect of biomass on food prices?
19. How should the available biomass be used?
20. What type of analyses is still needed?

The answer to the first question reads as one of the main conclusions of the study, so this is treated here in some detail.

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

In principle, biomass potentials are likely to be sufficient to allow biomass to play a significant role in the global energy supply system. Current understanding of the potential contribution of biomass to the future world energy supply is that the total technical biomass supplies could range from about 100 EJ using only residues up to an ultimate technical potential of 1500 EJ/yr potential per year. The medium range of estimates is between 300 and 800 EJ/yr (first column of fig ES.1 below). This assessment has provided several sensitivity analysis of available results to date, especially with respect to water availability, soil quality and protected areas. These are significant and led to corrections to earlier estimates of the resource potentials. Thus, the present study gave more insight in the various factors influencing biomass potentials tuning down the range of about 200 to 500 EJ/yr (second column of fig ES.2)

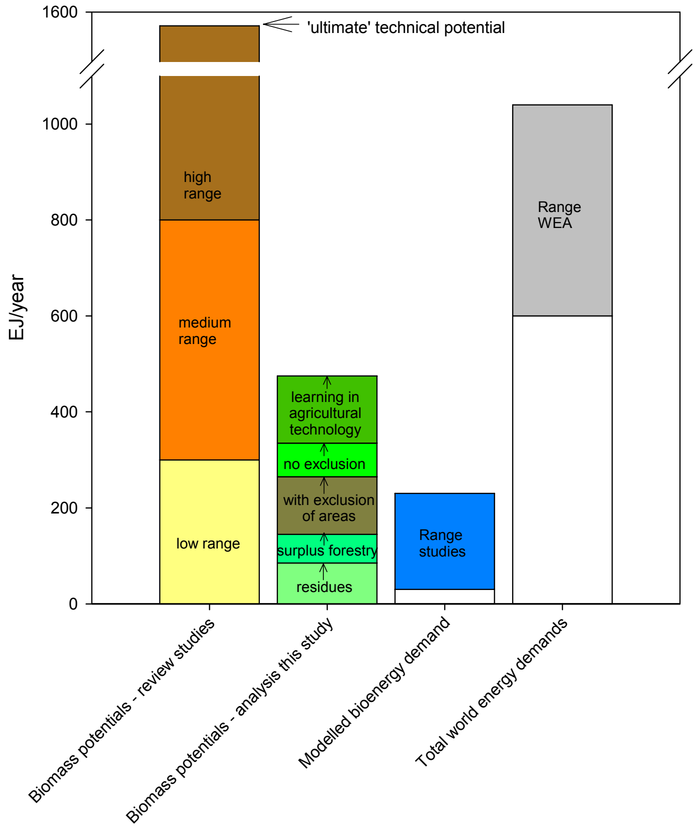


Figure ES.2 Comparison of biomass supply potentials in the review studies and in this study with the modelled demand for biomass and the total world energy demand, all for 2050.

The biomass potential, taken into account the various uncertainties as analysed in this study, consists of three main categories of biomass:

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

The three categories added together lead to a biomass supply potential of up to about 500 EJ.

Energy demand models calculating the amount of biomass used if energy demands are supplied cost-efficiently at different carbon tax regimes, estimate that in 2050 about 50-250 EJ/yr of biomass are used. At the same time, scenario analyses predict a global primary energy use of about 600 – 1040 EJ/yr in 2050 (the two right columns of fig ES.2).

7. Policy recommendations

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

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

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

The biggest challenge in realising the potentials of biomass production is in the design of proper strategies for management and implementation of production and management systems. Such strategies will allow the gradual introduction of crops for bio-energy production in rural areas, at the same time maintaining or even improving the productivity of agriculture. This study shows that productivity increase is an essential policy element, to prevent that competing claims on land use are being developed or large-scale competition leading to higher food prices. A successful policy targeting the development of bioenergy use and biomass production should incorporate a variety of targets and boundaries. Fulfilling a strict GHG criterion will lead to different choices for crops and land management compared to a situation where no criterion is formulated. This is also true for sustainable management of water resources, biodiversity, as well as rural development.

Clearly, the balance of objectives will be different from setting to setting (compare rural Africa with the EU for example) and in case (regional) trade-offs between various objectives have to be made. It is argued here that such trade-offs should be explicit, balanced and incorporate clear boundaries that should be respected and used as a starting point for developing biomass production in a given region. International and national policies, and identifying and deploying the right type of incentives (subsidies or obligations) must be designed to achieve just that in order to become successful in the end.

1 Introduction

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

Current global energy supplies are dominated by fossil fuels (388 EJ per year). Biomass provides about 45 ± 10 EJ, making it by far the most important renewable energy source used. Much smaller contributions are from hydropower (28 EJ) and nuclear power (26 EJ). On average, in the industrialized countries biomass contributes less than 10% to the total energy supplies, but in developing countries the proportion is as high as 20-30%. In quite a number of countries biomass supplies 50-90% of the total energy demand. A considerable part of this biomass use is, however, non-commercial and relates to cooking and space heating, generally by the poorer part of the population. Part of this use is commercial, i.e. the household fuel wood in industrialized countries and charcoal and firewood in urban and industrial areas in developing countries. An estimated 9 ± 6 EJ are included in this category. (WEA, 2000; WEA2004)

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

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

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

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

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

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

Focussing on the more recent estimates of biomass resource potentials, energy farming on current agricultural (arable and pasture) land could, with projected technological progress, contribute 100 - 300 EJ annually, without jeopardising the world’s future food supply. A significant part of this potential (around 200 EJ in 2050) for biomass production may be developed at low production costs in the range of 2 €/GJ assuming this land is used for perennial crops (Hoogwijk, 2004; WEA, 2000). Another 100 EJ could be produced with lower productivity and higher costs, from biomass on marginal and degraded lands. Regenerating such lands requires more upfront investment, but competition with other land-uses is less of an issue and other benefits (such as soil restoration, improved water retention functions) may be obtained, which could partly compensate biomass production costs. Combined and using the more average potential estimates, organic wastes and residues could possibly supply another 40-170 EJ, with uncertain contributions from forest residues and potentially a significant role for organic waste, especially when bio-materials are used on a larger scale.
Key to the introduction of biomass production in the suggested orders of magnitude is the rationalization of agriculture, especially in developing countries. There is room for considerably higher land-use efficiencies that can more than compensate for the growing demand for food (Smeets, et. al., 2007).

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

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

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

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

Main objectives of this assessment study:

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

Set up of the work:

- Part 1 comprises an extensive assessment of recent literature on the key areas distinguished: biomass potentials, food production, water, biodiversity, energy demand and analyses of agricultural economics. 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 are 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.

Main Report structure:

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

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

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

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

2 Results of the assessment activities

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

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

2.1 Biomass potential studies

2.1.1 Introduction

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

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

2.1.2 Review of studies

In this assessment we focus on the relation between estimated biomass potentials and the availability and demand of water, the production and demand of food, influence on biodiversity and economic mechanisms. For this purpose, we analyzed 8 recent studies (Table 2.1). None of these studies covers the whole range of issues, but they all have strong points at certain issues.

The scope of the studies, in terms of biomass resources included, varies as well as the scenario assumptions. As a consequence, global biomass potentials vary widely (Figure 2.1.1). The high biomass potential for 2050 determined by Smeets et al. (2007) shows potentials under intensive, very high technologically developed agriculture. On the contrary, the low biomass potential for 2050 calculated by Wolf et al. (2003) is caused by high population growth, high food demands and extensive agricultural production systems. The study of (Hoogwijk et al. 2005) refers to production of energy crops on abandoned, marginal and rest land assuming global and regional trends as described in the IPCC SRES scenarios, under increasing agricultural efficiency over time Finally, the study of Rokityanski et al. (2007) determines economic potentials of afforestation and reforestation, excluding other types of biomass and assuming extensive forestry management. As a result, the economic potentials for 2100 are rather low.

Table 2.1 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 modeled 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:* modeling 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 modeled
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 modeled
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

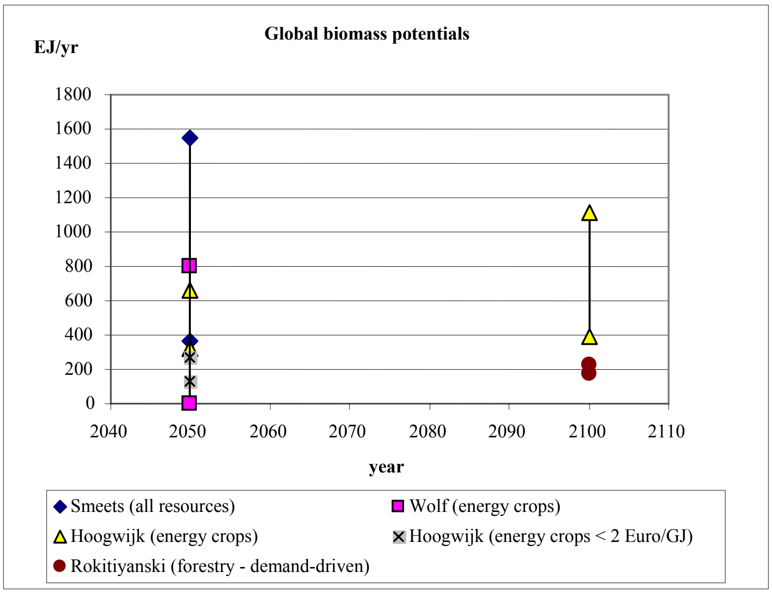


Figure 2.1.1 Ranges of estimated global biomass potentials

Reducing greenhouse gas (GHG) emissions is a major driver for using biomass for energy and materials. Many studies deal with GHG balances of biomass production and uses even though GHG emission reduction is not explicitly analyzed in the biomass potential studies reviewed. Most biomass chains turn out to reduce net GHG emission, but the results vary depending on the type of crop, the crop yields, the type of energy or material use, the fossil energy reference system and the land use changes involved. In general, second generation biofuels are more favourable than first generation biofuels as they tend to require lower energy inputs for biomass production and have a higher efficiency of biomass conversion.

2.1.3 Conclusions review biomass potentials

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

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

2.2 Biodiversity

2.2.1 Introduction

The global number of species has shown a fast decrease in the last few centuries, mostly through habitat loss and land-use change. The raised policy interest has led to two global UN Conventions that contain targets on preventing further biodiversity decline. The CBD

Convention wants to reduce the rate of further loss by 2010, and is focused on a broad range of causes for the decline, among which land-use changes. The Climate Convention (UNFCCC) has a long term goal to prevent damage to biodiversity from climate change effects, next to mitigating climate change itself.

Designing policy options and measures that may help to reach these short and long term targets (such as climate change mitigation through use of bio-energy) depend on the way the concept of biodiversity is implemented. Biodiversity includes the variability of all living organisms and all ecosystems. It is a complex phenomenon and can not be simply defined and measured. All possible indicators are imperfect to capture the full complexity, but they are useful if they can be monitored and explained, related to human impact and modelled to show future developments and the effects of policy choices. Several complementary indicators are therefore used within the CBD-framework. Different indicators might give different messages because of different definitions and implicit valuation of biodiversity, for instance when indicators based on “naturalness” or contrary on “agro-biodiversity” are used.

Bio-energy potential studies conducted so far mostly neglect the effects of biofuel production on different biodiversity indices. An ideal study should take all relevant biodiversity aspects and scales into account, and should not only show local effects, but possible shifts and trade-offs to other locations as well. Several types of impact assessment studies can be distinguished:
1. Assessing local and present impacts of bio-energy cultivation.
2. Assessing integral, global impacts of bio-energy in an LCA-approach, comparing the effects of biofuels and fossil fuels over the whole production chain on greenhouse gas emissions, land-use and biodiversity effects.
3. Regional and global scenario studies, showing the integral and future effects of bio-energy, in combination with other global developments in population growth, food demand, diets and agricultural productivity.

2.2.2 Review of studies

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

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

biofuels the overall impact on biodiversity is very likely to be negative. For none of the biofuels a positive impact can be guaranteed.

General scenario studies
There are no global scenario studies that take all relevant aspects of the biofuel debate into account. Several issues were treated in a global study (CBD and MNP, 2007), undertaken by MNP for the CBD's 2nd Global Biodiversity Outlook (CBD, 2006). The analysis contained an ambitious climate change option with a broad measure portfolio, including large scale use of bio-energy. The aggregated indicator MSA ("mean abundance of original species") was applied to express global biodiversity loss, which can be interpreted as a measure of naturalness or ecosystem intactness. The indicator is not intended to highlight individual species, agro-biodiversity or the specific value of protected areas. The analysis indicated that increased land-use of mainly abandoned land and marginal grounds for growing bio-energy crops leads to biodiversity losses on the short term (as compared to a baseline scenario, in which abandoned lands will restore to more-or-less natural situation). By 2050, the increased loss is not yet counteracted by biodiversity gains through avoided climate change. In determining whether short-term losses can be balanced by long-term gains, uncertainty should be taken into account. Long-term effects are based on modelling exercises that are surrounded with considerable conceptual and data uncertainty. The local and specific characteristics and biodiversity values of the economically defined "marginal grounds" are also not well known. Further, there is uncertainty on the assumption on fast and complete biodiversity restoration on abandoned land.

2.2.3 Conclusions review biodiversity

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

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

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

2.3 Water

2.3.1 Introduction

Quantification of the spatial and temporal distribution of river runoff and assessing the influence of humans form the backbone for decisions on optimal use of water resources. A common classification of water resources is the classification into blue and green water flows. Blue water refers to water in rivers, lakes and groundwater. Green water refers to water in the rooted zone of the soil originating directly from rainfall that is available to plants. Globally around 80% of agricultural evapotranspiration (crop water depletion) originates from green water, while the remaining 20% is provided through irrigation (blue water withdrawals) (Molden et al., 2007). 20-50% of blue water, depending on the local situation, is required for environmental requirements and services. In addition, water is required for industrial and domestic use.

At the regional and local scale, for blue water *irrigation efficiency* is a major determinant of water use. It is often defined as the net crop water requirement for evapotranspiration as part of the water withdrawn from a water source. A typical value would be 40%. Most of the other 60% is captured and recycled somewhere else in the system. As reuse loops of water are very common in river basins, improving irrigation efficiency becomes a very complex issue. *Water productivity* (WP) indicates the efficiency of water use, including blue water, if irrigated, and green water. Crop WP (CWP) is an indicator of crop yield per unit of water consumed (evapotranspiration). This implies CWP depends on the main product. If the plant parts used for energy and food are not the same, CWP of a crop differs for both purposes. Water use by crops can be estimated based on weather data and crop growth modelling or by a crop specific *Water Use Efficiency (WUE)* that varies among crops and crop types (C_3 - C_4 crops, annuals - perennials, herbaceous - woody species) and also with weather (rainfall, temperature, radiation) and agricultural management, such as input use and other practices. WUE can refer to evapotranspiration, transpiration, total crop yield, economic product, etc. Hence, caution is required when using data from literature (Bessembinder et al, 2003).

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

2.3.2 Review of studies

Expected future water use by industry and domestic sectors differs between different sources, as assumptions on technological development (efficient systems), economy and life-style vary among these sources. Some studies expect it to be more or less constant (Alcamo, 2003) and others expect it to increase by 60-220% (Shlikomanov, 2000). However, the largest part of this use (80%) flows back to rivers, lakes or groundwater. For agricultural water withdrawal, estimates vary considerably depending on the scenarios on population growth, human diet and input levels used. However, in all scenarios total water use is increasing. Energy crops are not considered explicitly in most studies.

Wolf et al. (2003) and Berndes (2002) estimate the effect of expanding the area under biomass crops taking into account both rainfed and irrigated agriculture. Wolf et al. (2003) conclude that the area available for energy crops varies between 0 and 45% of the present agricultural land, depending on the assumed scenario, i.e. human diet, input level and population growth. Berndes (2002) shows that under a biomass-intensive scenario similar trends can be expected for energy crops as the other studies showed for food crops, but stronger: increasing water scarcity in most regions, with the largest effects in the regions that are already water scarce. Increasing evapotranspiration is the main factor and irrigation of energy crops would increase water scarcity.

Total blue water requirements and availability, including the environmental water requirements (EWR) have been expressed in a water stress indicator by Smakthin et al. (2004); Figure 2.3.1. These estimates are in line with other sources. (Shlikomanov, 2000; Molden et.al, 2007)

All studies give solutions or directives for improving water use efficiency at given scales, both for irrigated and rain-fed agriculture. It is generally acknowledged that considerable improvements can potentially be realised. Measures to alleviate water stress include increased recycling of industrial and domestic water, change of diets towards less water consuming foods and less meat, improve agricultural water productivity by reducing runoff, water harvesting, supplemental irrigation and better maintenance of irrigation systems; the latter measures specifically increase the use efficiency of blue water.

At the field scale, high water use efficiency (WUE) of crops can only be achieved if other factors (nutrient availability, incidence of pests and diseases, appropriate and timely management) are not limiting crop production to a larger extent than water. In that case evaporation (unproductive water loss) is minimized and transpiration (productive water use) is maximized. Hence, optimal input use and soil management increase the efficiency of green (and blue) water use. In different regions of the world large variations in actual crop WUE are reported resulting from variations in these factors (Molden et al. 2007). Hence, in estimating opportunities for energy crops, the strong interaction between water, nutrients and management has to be taken into account. In practice, crop production systems in a region, steered by local climatic, edaphic, economic and social conditions, show large differences in input use and efficiency as compared to otherwise comparable systems in other regions.

Climate change is very likely to change rainfall patterns while increasing temperatures will influence water transpiration and evaporation. The net effect is not easy to predict and will show large variations among different regions of the world. Especially semi-arid and arid areas are expected to suffer from reduced water availability caused by a combination of increasing precipitation variability, increased water use by crops, and reduced groundwater recharge. Problems are further expected in river basins depending on glacier or snowmelt-fed rivers while sea level rise may lead to increased salinization of groundwater and estuaries. While positive effects of climate change on freshwater systems will occur, on the whole, negative effects will outweigh the benefits. There are signs that the impact on irrigation systems may be very strong, generally limiting irrigation water potential.

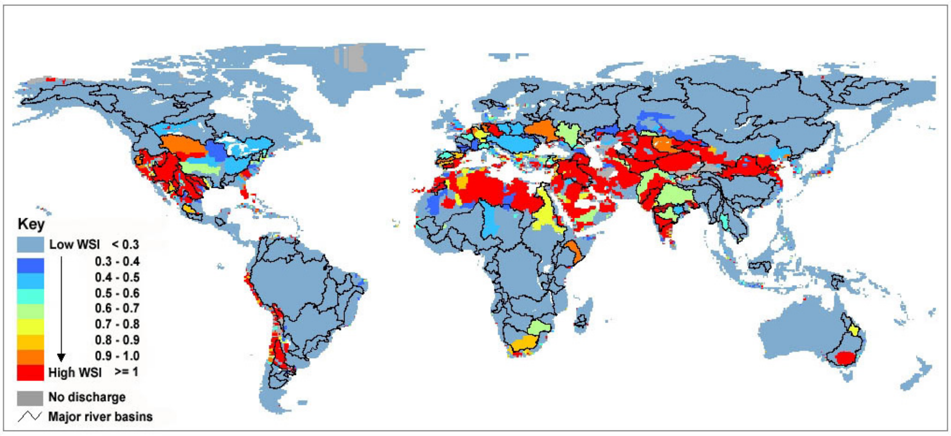


Figure 2.3.1 Water stress indicators (Smakthin et al., 2004)

2.3.3 Conclusions review water demands and availability

Comparing the different analyses shows that problems are analysed at a higher scale than the solutions formulated. The large variability in regional climate and hydrology asks for a detailed and local analysis of the biophysical possibilities for crop production. The studies analysed show that conditions show large differences among different regions. In some regions abundant water availability provides ample opportunities for energy crop production, while water scarcity in other regions is seriously restricting any opportunity for energy crops.

To determine water availability for energy crop production a basin scale seems most appropriate in order to assure that the interaction between upstream and downstream water availability and use is taken care of. A suggestion is to execute the following steps:
- estimate renewable water resources on the scale of a 'river basin' area
- determine how much water is required for food and feed crop production related to local production systems and regional developments and estimate future projections
- estimate the environmental water requirements
- verify the available land area for additional (energy) crop production
- assess the regional and crop(type) specific WUE of the energy crops to be cultivated
- assess whether water availability or land area is a limiting factor for bio-energy production for different parts of the river basin.

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 only been done incidentally, 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 water is available and if it can really be used cannot be determined based on available studies. Future change in rainfall patterns will regionally have a large impact, especially in regions that are already water scarce.

Climate change is likely to change rainfall patterns while water transpiration and evaporation will be enhanced by increasing temperatures. The net effect of this is not easy to predict, large variations can be expected among different regions of the world. Especially semi-arid and arid areas and are expected to be confronted with reduced water availability, while problems in many river basins may be expected to increase. On the whole, negative effects of climate change will outweigh the benefits for freshwater systems, adversely influencing water availability in many regions and hence irrigation potentials.

2.4 Food

2.4.1 Introduction

Technologically speaking, producing enough food for even 10 billion people seems feasible (Evans, 1998). In contrast, doing so without compromising sustainability – both by pollution and by resource depletion – will be a formidable challenge (Tilman et al., 2002). Currently, *food production* appropriates about 75% of the available freshwater and 35% of the global land area (Smil, 2002a: 239). While the world population doubled during the second half of the 20th century, in consequence of increasing incomes, its appetite for meat quadrupled, requiring 40-50% of the world grain harvest to be fed to livestock (Evans, 1998). Within the food domain, meat production has a disproportionate environmental impact (Aiking et al., 2006) and, therefore, environmental impacts of food production are strongly coupled to actual diets.

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

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

2.4.2 Review of studies

Food demand

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

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

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

Food production

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

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

2.4.3 Conclusions review of food demand and production

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

2.5 Energy demand

2.5.1 Introduction

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

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

2.5.2 Review of studies

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

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

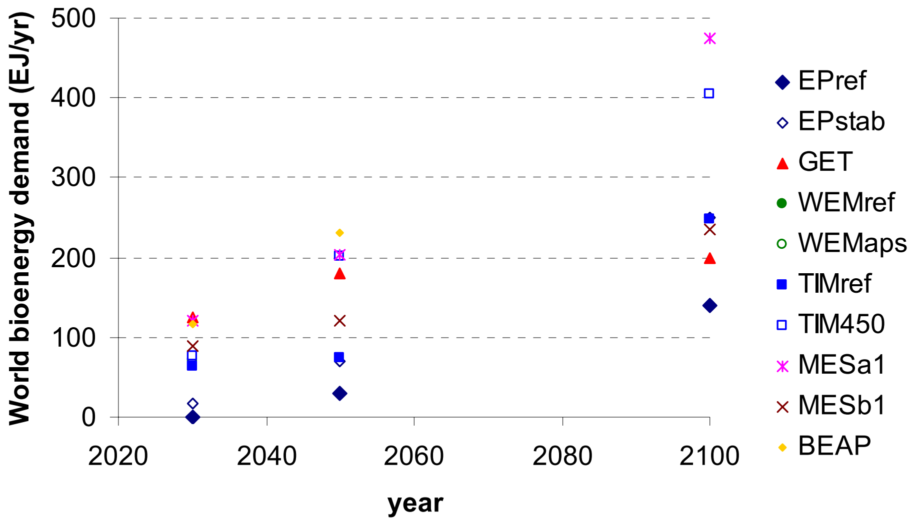


Figure 2.5.1 Biomass demand for energy (EJ/yr) in the different global energy scenarios.

2.5.3 Conclusions review energy demand models

Projections of global demand for biomass by 2100 indicate that we should think of amounts in terms of hundreds of EJ, with a minimum of 150 EJ (in a conservative reference scenario without any climate policy) and a maximum above 400 EJ (in a biomass-intensive scenario with active climate policy). For the year 2050, this range is between ca 50 and 250 EJ.

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

2.6 Agricultural economics

2.6.1 Introduction

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

2.6.2 Review of studies

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

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

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

2.6.3 Conclusions review economic models

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

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

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

3 Integration of knowledge from assessment areas

3.1 Introduction

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

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

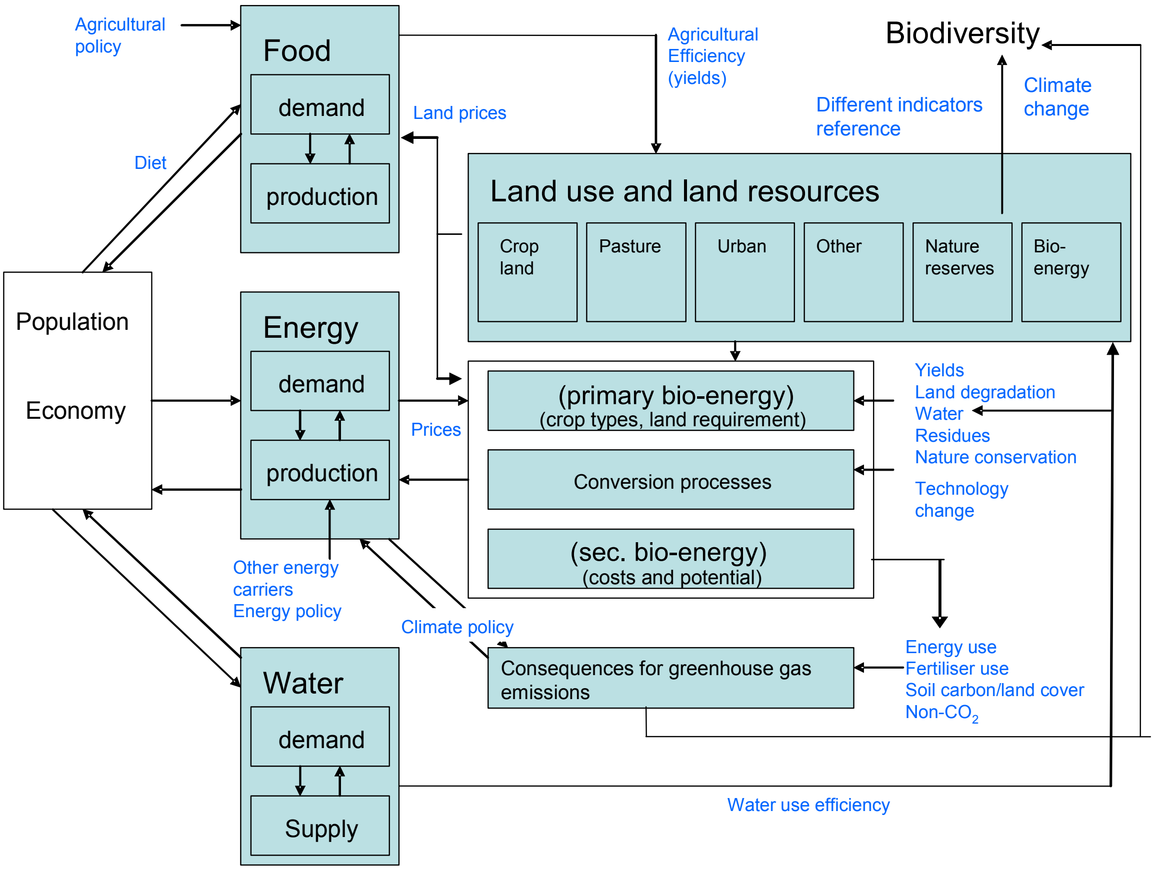


Figure 3.1.1 Overview of some key relationships and assumptions relevant to assess potential bio-energy supply. The figure is only meant as indication (e..g other relationships also exist and scientific disciplines may order to information differently).

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

The analysis concentrates on five main issues:
1. The role of bio-energy use in energy models; in particular to identify which factors can limit penetration of bio-energy (potential for bio-energy; long-term cost-supply curve; energy use in specific sectors);
2. The sensitivity of bio-energy potential estimates to issues such as uncertain development of agriculture technologies, land use, water scarcity, land degradation and nature reserves;
3. Key uncertainties in assessing biodiversity losses as a result of land conversion for bio-energy;
4. The economic link between food, feed and fuel;
5. Key results and uncertainties in impacts on greenhouse gas balances.

3.2 Limiting factors to bio-energy use in energy models

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

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

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

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

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

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

The effect of competition with other energy options is also illustrated by some scenario runs with variation of CO_2 taxation. For example, in TIMER and MARKAL runs in which we increase a CO_2 tax and thereby the share of biomass in the primary energy mix, biomass does not reach its maximum supply potential. In the TIMER analysis of overall system response to an increase in CO_2 taxation (Annex 1 section 1.1 and 1.2), biomass use in 2050 increases at low CO_2 taxation levels, but stabilizes at a level of circa 130 EJ at taxation levels above $100 / tonne carbon (see Figures 3.2.1 and 3.2.2) (The 130 EJ needs to be compared to a total energy consumption of 550-700 EJ, thus around 20% of energy demand are provided by bioenergy.).

IEA's World Energy Outlook indicates a 10% share of bio-energy in total energy consumption in 2030 that could be increased to 11% with climate policy). The stabilisation of bio-energy at higher taxation levels is because other energy options displace additional use of biomass under these circumstances. Biomass supply potential is not the limiting factor here, since this reaches up to 400 EJ in 2030 already; see Annex1. Apparently, the more expensive part of biomass feedstock does not enter the market due to other options such as coal with CCS or other renewable options being more cost-effective, even with a CO_2 tax.

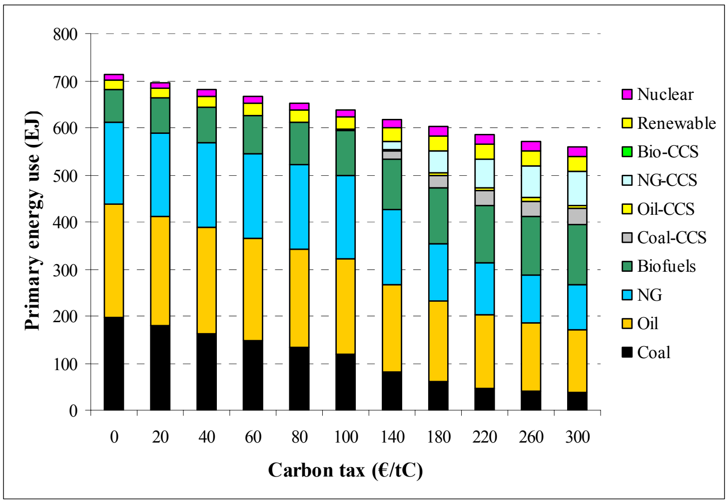


Figure 3.2.1 Overall world energy mix in 2050 at increasing CO2 taxation in a representative TIMER scenario.

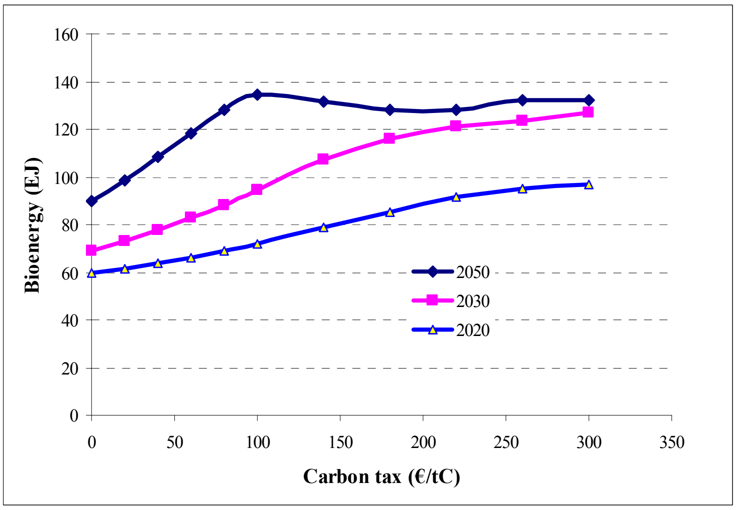


Figure 3.2.2 The supply of biomass in 2020, 2030 and 2050 as a function of carbon taxation in a representative TIMER scenario.

Especially in the *power generation sector*, biomass-based options compete with several other technologies that also have lower emissions than fossil fuels[1]. From an indicative analysis (i.e. not taking into account dynamic depletion/technology development impacts) with the TIMER technology database (Annex 1 section 1.3), the costs of biomass feedstock (at farm gate) were calculated as a function of the CO_2 taxation level. It appears that biomass feedstock for this sector should have costs in the order below 3 US$/GJ by the year 2020 to be fully competitive at carbon prices below 100 US$ per tonne CO_2, and below 4 US$/GJ at carbon prices beyond this point. In 2050, the situation is somewhat changed due to the cost decline of one of the

[1] The greenhouse gas balance of bio-energy is discussed further in this chapter.

competitors, i.e. coal-CCS. As a result, bio-energy costs now need to be below 2-3 US$/t$CO_2$ over the whole range to remain competitive. This is consistent with the marginal cost of the electricity mix (i.e. the price of the marginal kWh of power to which a bio-based option must be competitive) as given by the 2050 MARKAL CM scenario with a CO_2 taxation of € 100 /tonne CO_2 (see Annex 1 section 2.2).

In the *transportation sector*, the common competitors of bio-energy are fossil oil based fuels, with natural gas and the hydrogen fuel cell as (innovative) options. Here, the competitiveness of bio-energy therefore depends on oil prices and the price of CO_2. At oil prices of 40 $/bbl, a TIMER analysis (Annex 1 section 1.3) indicates that primary biomass costs (at farm's gate) in the order of 4-5$/GJ are competitive at a carbon price of 150 $/ton carbon and higher. At higher oil prices, a lower carbon price would be required to make bio-energy competitive. It should be noted that for the 1st generation biofuels (food crops), the costs of feedstock typically account for a majority of the production costs, while for 2nd generation biofuels (cellulose conversion to ethanol) are more important. As the most important costs reductions are expected for conversion, in the long run more room for improvement is expected from these 2nd generation fuels.

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

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

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

Technological learning will improve opportunities for bio-based options significantly, but the same applies to other innovative technologies, such as CO_2 capture and storage and the hydrogen fuel cell. Therefore, it is relatively difficult to assess what impact overall higher or lower learning rates will have. Furthermore, estimation of learning rates, as well as production volumes and market sizes in which technologies learn are still subject to debate in the scientific arena. In an indicative MARKAL run with overall faster learning rates for selected conversion technologies in EU15 (Annex A1.2.2), the role of bio-based options remains relatively unchanged. In the power generation sector, it is mainly solar power that profits from improved learning, mainly at the expense of coal-based power. This is due to the fact that solar technology has a significant learning potential and conversion technology is the dominant cost factor in the cost build-up (see Figure 3.2.3). In the transportation sector, improved learning leads to a strong introduction of the hydrogen fuel cell, at the expense of natural gas (see Figure 3.2.4 In this sector the hydrogen fuel cell vehicle has a significant learning potential because the technology is still immature, and the fuel cell costs form a major part of the cost build-up per driven km. Introduction of the hydrogen fuel cell vehicle could induce an increased demand for biomass, since this hydrogen can be produced out of biomass. This production route will compete with fossil-based routes (coal, natural gas), including combinations with CCS, and possibly with production on the basis of renewable electricity.

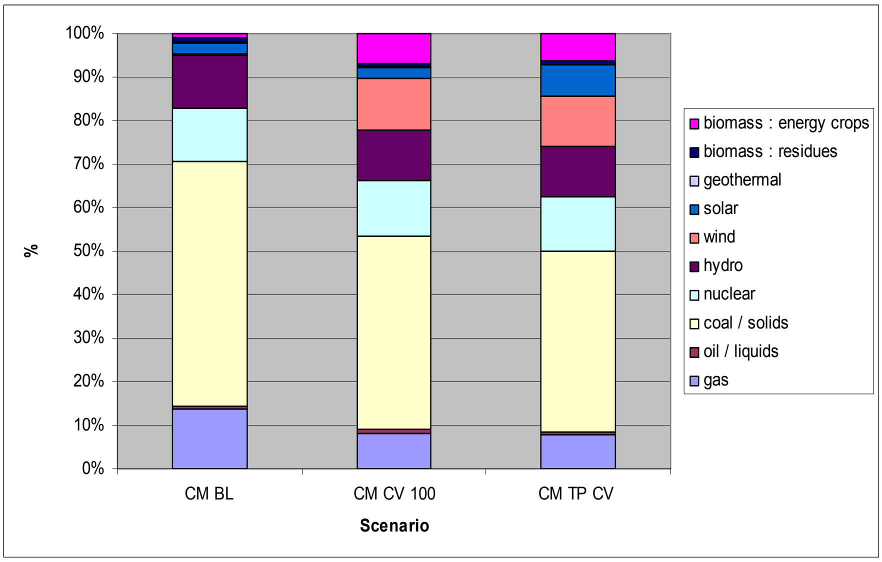


Figure 3.2.3 Shares of different technologies in net electricity generation in the EU15 in 2050 in a MARKAL baseline scenario (CM BL), a scenario with a CO2 taxation of € 100 /tonne (CM CV 100) and a scenario with the same taxation and improved technological learning (CM TP CV).

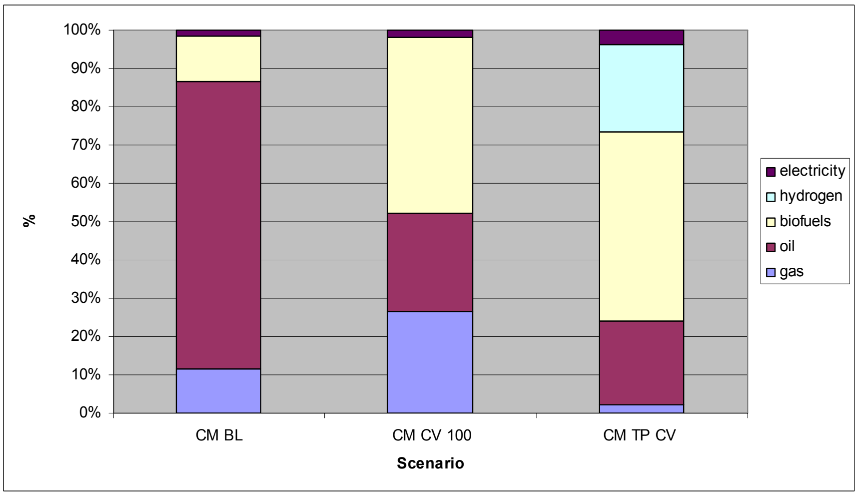


Figure 3.2.4 Shares of different technologies in transportation in the EU15 in 2050 in a MARKAL baseline scenario (CM BL), a scenario with a CO2 taxation of € 100 /tonne (CM CV 100) and a scenario with the same taxation and improved technological learning (CM TP CV).

3.3 Impacts of some key uncertainties on bio-energy potentials

Estimating bio-energy potentials in IMAGE

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

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

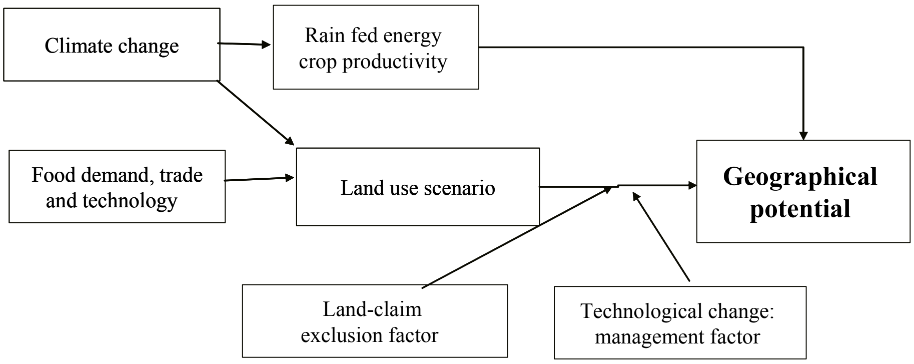


Figure 3.3.1 Methodology of assessing bio-energy potentials

The potential for bio-energy determined thus concentrates on 2 areas:
- abandoned agriculture land (in the short term mainly in developed regions; but later on also in some developing regions)
- natural grass ecosystems (an exclusion factor of 50% is used here, leading to an expansion of total arable area; but outside forest)

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

Below, we apply the Hoogwijk method and look into the following uncertainties:
- Impact of different scenarios
- The role of different crops and land areas
- Water scarcity
- Land degradation
- Nature reserves

It should be noted that many global land use scenarios show potential land abandonment in parts of the world (e.g. the Millennium Ecosystem Assessment, several scenarios assessed in the recent IPCC AR4 report, the IPCC SRES scenarios). Nevertheless, from an economic perspective this feature is sometimes questioned as lower land prices would slow down the incentive for agricultural yield improvement. The scenario taken here as central case does have the feature of land abandonment.

Finally, in Hoogwijk's original application nature reserves existing in 2000 were excluded from potential biomass production. Here, to explicitly analyse the influence of biodiversity restrictions this assumption has only been added in the discussion on nature reserves.

Impact of different scenarios

The analysis of Hoogwijk concentrated on the geographic and economic potential of woody biofuels- using the IMAGE implementation of the IPCC SRES scenarios as a basis. Given new insights into possible future changes, here instead use **the reference scenario of the Netherlands Sustainability Outlook and the OECD Environmental Outlook (DV-2 or OECD baseline)**[2]. This scenario should be regarded as a 'medium-development' type of scenario (in terms of population and economic change, but also agricultural productivity change). GDP per capita grows globally by about 2% per year, while the global population reaches a level of 9.4 billion people in 2050. Changes in agricultural yield and consumptions patterns are based on the FAO projections (Bruinsma, 2002). The resulting agricultural land worldwide (including extensive grassland) increases from 4.9 Gha in 2000 to 5.5 Gha in 2050 (excluding extensive

[2] The reference scenario of the DV-2 is based on work that has been performed jointly by the OECD and MNP, and also forms the reference scenario of the OECD Environmental Outlook that will be published in 2008.

grassland, these numbers are 3.8 and 4.4 Gha). The extension of agriculture land occurs almost exclusively in developing countries, while land use in OECD countries remains more or less stable. Compared to the IPCC scenarios, in terms of most assumptions, the scenario lies in between the A1b (high economic growth) and B2 (medium assumptions) scenarios. As shown earlier by Hoogwijk et al. (2005) and Smeets et al. (2007), scenario-related assumptions, such as for population growth, food demand, agricultural trade and technology change, are very important for the potential for bio-energy. The potential for bio-energy as calculated using the methodology indicated in Figure 3.3.1 on the basis of the OECD baseline scenario in 2050 is around 200 EJ. (In other words, the total area of abandoned agricultural area and natural grass ecosystems, taking into account the 50% exclusion factor, could produce 200 EJ of primary bio-energy). Using the land use patterns of the IPCC SRES scenarios (but keeping other factors, such as assumed bio-energy yields and land-claim exclusion factors the same as under the OECD baseline scenario) would lead a range from 120 to over 325 EJ (with low potentials in A2 as a result of a high population growth, low yields and little trade; and high potentials in A1 and B1 as a result of low population growth and rapid yield change).

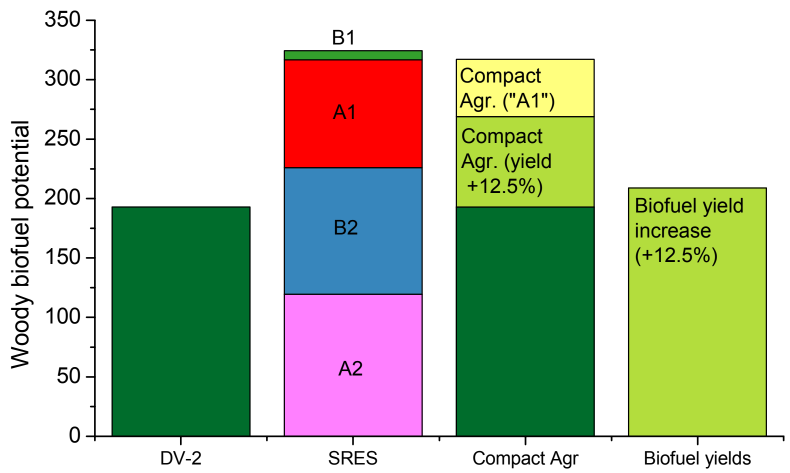


Figure 3.3.2 Potential for primary woody bio-energy (not including residues) and using different scenario assumptions

An important factor in these calculations are the assumed changes in yields. This is also shown in Figure 3.3.2 by showing the two alternative cases that look into a more compact agriculture compared to the OECD baseline (DV-2) scenario (and thus higher yields). In the first, agricultural yields are improved for all crops and regions by 12.5% compared to the base case. The value of an additional increase of 12.5% is equal to half the suggested improvement potential compared to baseline in the International Assessment of Agriculture Science and Technology Development (IAASTD, forthcoming). The second scenario of more compact agriculture applies the same convergence in agriculture yields world-wide as in the A1 scenario, i.e. bringing 2050 technology levels in developing countries close to current Western European levels – while keeping the baseline improvement for developed countries. Both cases lead to a considerable increase in potential compared to the OECD baseline scenario: 40% for the first case and about 65% for the second. In other words, assumed yield changes for agriculture in general critically determine the potential for bio-energy. Assuming a more compact agriculture could possibly lead to about 300 EJ/yr of primary woody bio-energy in 2050. It should be noted, however, that yield improvement could obviously also be slower than our base case assumptions. Furthermore, these calculations are single-factor variations: the changes in yields discussed here are likely to impact land and food prices, and could therefore lead to indirect effects.

Obviously, also the yield increases for biofuel crops are uncertain. The assumed increase in the base case is based on yield estimates by Hoogwijk (2004) and strongly varies per region (as 2000 yields are very different for different regions). Globally, these values lead to a 100% improvement for woody biofuels (assuming a low 2000 starting value). Assuming an additional improvement in yields of 12.5% (now without improving the yields of other crops above the baseline) leads to an increase of total potential compared to the OECD baseline scenario by 12.5%. This implies that in general the yield increases for food crops have a stronger impact on bio-energy potentials than the yield increases for bio-energy crops specifically.

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

Here, we were only estimate the (primary) potential for woody crops and sugar, shown in Figure 3.3.3 on both abandoned agriculture land and natural grassland. The potential on abandoned agriculture land increases over time – with more abandoned land becoming available. The potential on natural grassland is mainly a function of yields as the area of natural grassland is more constant. Worldwide, the potential for woody and sugar bio-energy is considerable. Sugar has very high yields in developing regions. The type of fuel chosen does obviously depend strongly on relative prices of crops, animal feed and food. In most cases, woody biofuel seem to become the most dominant feedstock worldwide of the two options evaluated here.

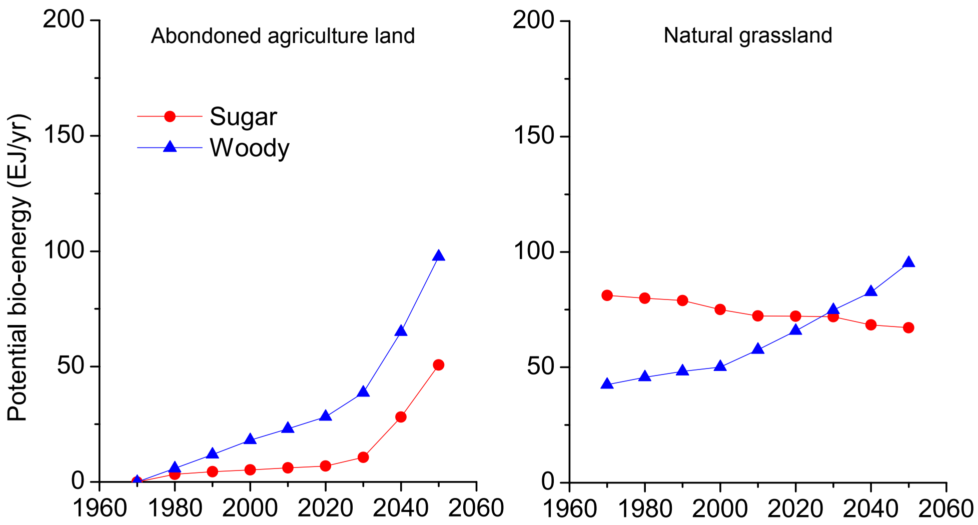


Figure 3.3.3 Potential for primary bio-energy on different crops and land-types in the OECD baseline (DV-2) scenario (potential cannot be added, as the same grid cell might be used for both the sugar and woody bio-energy potential). Natural grassland comprises natural ecosystems that would be converted into agricultural land.

Water scarcity
All calculations on bio-energy potential have been carried out assuming rain-fed production conditions. On the one hand, this can be regarded as an underestimation given the fact that irrigation could increase yields. On the other hand, IMAGE calculations do not take into account that other sectors than agriculture may also use (the same) water resources. In order to assess the potential impact of water scarcity on bio-energy potentials, here we use a map of the water stress indicator as calculated by the University of Kassel using the WaterGap model (Alcamo et al., 2003) on the basis of the same scenario as used for our bio-energy calculations (thus based on the same socio-economic, land use and energy scenario). The water stress indicator is defined as the total actual water withdrawals as proportion of the maximum available runoff minus environmental water requirements. Values of this index of 0.2 and higher is defined as modest water scarcity, while values above 0.4 are defined as severe water scarcity. (Smakthin et al., 2004) Some authors have tried to assess the impacts of water scarcity on bio-energy potential before, showing that while impacts are not dramatic on a global scale, on a more local scale water scarcity may clearly limit bio-energy potential (see Chapter 2).

To assess the possible impact, here a simple overlay is made between the bio-energy map with the water stress indicator maps of the WaterGap model [3]. This overlay suggests that about 15% of the total potential for bio-energy is in severe water scarce areas (and might therefore be excluded), and another additional 5% in modest water scarcity areas (Figure 3.3.5). It should be noted that to fully analyze the potential impacts of bio-energy on water scarcity, a better approach would be to calculate the water demand of potential bio-energy areas (using the water demand factors discussed in the integration analysis (see Summary Section 2.6) and evaluate the impact of increased water demand at grid or watershed level.

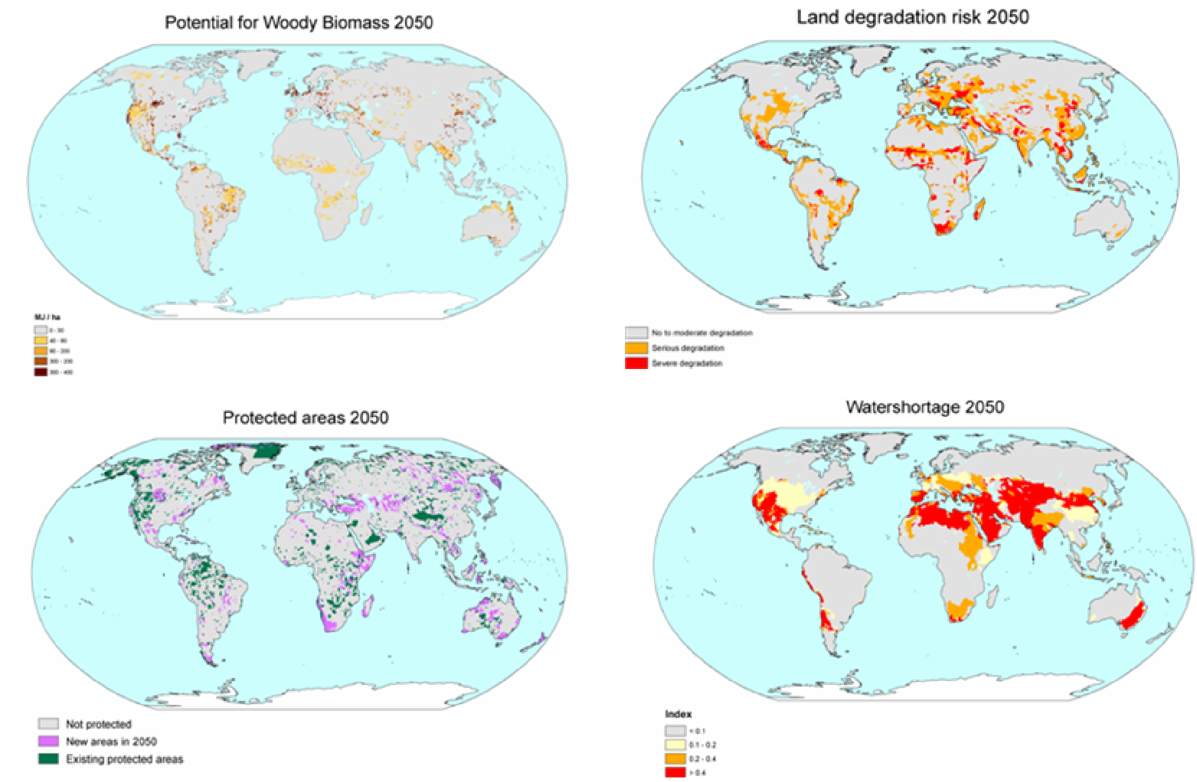


Figure 3.3.4 Maps of potential for woody bio-energy production in 2050, land degradation (map from the GLASOD database), protected areas (Sustainability First scenario GEOIV) and the water stress index (WaterGap results for 2050) as used in the analysis.

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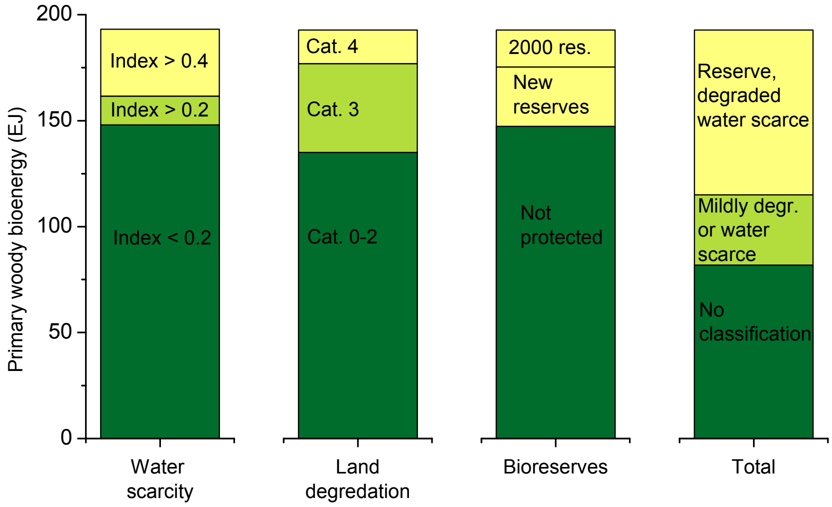


Figure 3.3.5 Impacts of sensitivity analysis on 2050 potential for woody biofuels

Degraded areas

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

- First, while abandoned agriculture areas are mentioned as a source for land for bio-energy, some of these areas are likely to suffer from land degradation. In fact, dependent on the degree of the degradation the soil might lose its function for biomass production or its function as substrate for natural vegetation. Reclamation of degraded soils into suitable land for production or into natural vegetation can be difficult.
- For less severely degraded areas, some people argue that by using these areas extensively (for bio-energy production), it is possible to enhance soil recovery. In this case, these areas would be prime expansion areas with little biodiversity impact as original vegetation cannot automatically recover. Whether this is actually possible needs to be looked into further, but using degraded land for production might need considerable inputs and investments, while it also might lead to benefits in view of recovery, biodiversity and biomass production.

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

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

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

Biodiversity/nature reserves
Another important relationship exists between conservation of biodiversity and bio-energy use. It should be noted that already in all calculations so-far forest areas and 50% of natural grasslands (implemented for each grid cell) have excluded for reasons of biodiversity conservation. However, still bio-energy use could lead to a reduction of biodiversity (converting natural grass land to bio-energy crop area for instance). In order to provide some insight into the impact of further biodiversity restrictions on bio-energy potential, we have used maps of 1) nature reserves in the year 2000 and 2) areas designated to become nature reserves under the Sustainability First scenario of the Global Environmental Outlook of UNEP (it should be noted that in the original work of Hoogwijk and other IMAGE applications, nature reserves existing in 2000 are mostly already excluded from estimates on bio-energy potential). Under the Sustainability First scenario, most of the biodiversity hot-spots are brought under protection – while the scenario also aims to protect sufficient areas of different eco-regions. Impact on bio-energy potential is considerable. Excluding reserve areas in 2000 reduces the total bio-energy potential by around 10% - while excluding the (very ambitious) expansion of reserves by 2050 would reduce the potential by another 15%. In total, this may lead to a reduction of bio-energy potential by 25%.

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

Figure 3.3.6 summarizes the findings of the analysis in a different way by showing the 2020 and 2050 total potential for biofuels and electric power using a crop mix that leads to maximal potentials for the production of biofuels or electric power. Results are given in terms of primary (before conversion) and secondary energy content after conversion: the actual energy produced in the form of biofuels or electric power. In each case, the first column indicates the most optimistic estimate for potential assessed here assuming the compact agriculture case and the 12.5% increase in yields for bio-energy crops. The second column shows the potential under the default OECD baseline (DV-2) scenario case and finally the third column provides an indication of the potential after conversion. For each column, the white area indicates the part of the potential that might be excluded as it is either 1) severely degraded, 2) under severe water stress or 3) potential nature reserve, while the green area indicates the remaining potential (for the individual impact of these factors see Figure 3.3.5). The total potential for biofuels slightly exceeds that of electric power as here in some cases more productive crops are used (sugar; selection on lowest production costs).

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

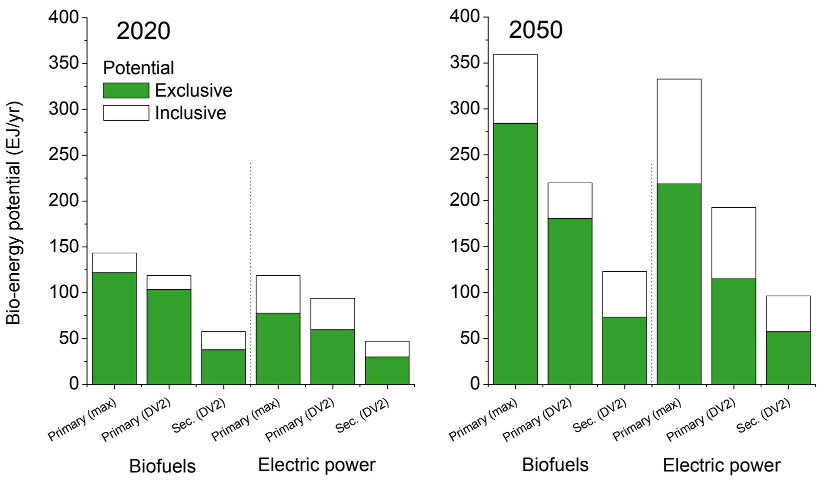


Figure 3.3.6 Potential for bio-energy, primary and secondary. Inclusive refers to the original estimates not accounting for restrictions discussed in the previous sections (i.e. soils with degradation or water stress). The exclusive potential does exclude severely degraded soils, areas under severe water stress and nature reserves. The potential for secondary energy takes into account the conversion from primary energy into secondary energy carriers (fuels and electricity). Note that the potential for biofuels and electric power cannot be added as they refer to the same area.

Obviously, the potential for bio-energy is pretty meaningless without an assessment of the associated production costs. On the basis of additional assumptions on capital and labour costs for production and conversion of bio-energy and transport costs – it is also possible to estimate the costs curves for both biofuels and (bio) electric power (Hoogwijk, 2004; Van Vuuren, 2007). The formula (a Cobb-Douglas production function) and assumptions made by Hoogwijk (2004) are here applied at the grid level – calculating production costs as a function of GDP per capita (as proxy of labour costs), capital inputs and yields. Both yields and GDP are assumed to improve of time (consistent with the scenario discussed so-far). The curves move out over time (as potential increases) and tend to move along the y-axis. The latter shows both an increase (as a result of labour costs increase) on the low side and a decline (as a result of technology progress on costs) on the high side. The curves assessed on the basis of the information presented here are shown in Figure 3.3.7. These curves can be compared to the information discussed in Section 3.2. It should be noted that adoption of bio-energy in the energy system will not be based on primary bio-energy costs (as calculated here) but on the basis of the costs of different fuel types. The costs of conversion is often more dominant in this.

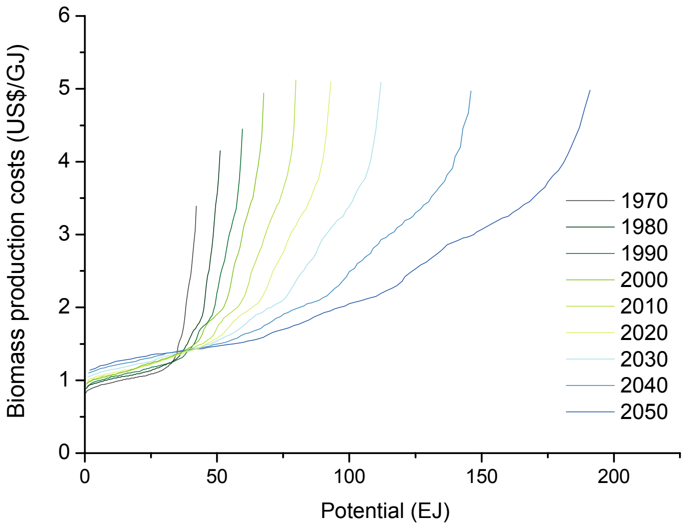


Figure 3.3.7 Cost curves for biofuels

3.4 Biodiversity consequences of bio-energy use

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

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

The OECD scenario for the Environmental Outlook (OECD, in prep) serves as a background for this exercise. In the OECD baseline scenario, biodiversity declines by 11% between 2000 and 2050 (expressed in MSA). For an ambitious 450-ppm option for climate change mitigation, large scale bio-energy production is implemented with mainly woody biofuels. For this, 1.8 million km^2 of abandoned agricultural land is used, and a further 3 million km^2 of extensively used grasslands (considered having a semi-natural character) are converted. Compared to the baseline, the total biodiversity decline in the option is 1% less (relative difference of 10%).

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

1- Growing bio-energy crops on natural areas (converted forests and natural grasslands) will lead to large biodiversity losses. Agricultural crops lead to a loss of - 3.1%, woody biofuels to -2.7%, and agro-forestry systems to -1.8%.
2- Using abandoned areas will lead to lower local biodiversity losses. We assume that these areas would be otherwise be used for nature restoration (leading to partially recovered nature in 2050). Using these abandoned areas will then lead to losses of -1.3% for agricultural bio-energy crops, -0.9% for woody biofuels, and no net loss for agro-forestry. In the OECD climate change option, a large part of bio-energy production is allocated on extensively used semi-natural grasslands. These grasslands may contain valuable biodiversity, as is the case for European High Nature Value farmlands (mostly grasslands) that are important for conserving agro-biodiversity. Temperate grasslands present a category that is underrepresented and falls short of the 10% target for global Protected Areas (IUCN and UNEP-WCMC, 2003). More knowledge on the global extent and biodiversity status of extensive grasslands, and their attractiveness for biofuel production is needed to better assess this subject.
3- Agricultural areas contain a relatively low local (residual) biodiversity. Replacing these crops with woody biofuels leads to a local biodiversity increase of + 0.5%, and using mixed land-use systems (agro-forestry) leads to an increase of + 1.4%. However, this local biodiversity effect neglects the possible shift in production area for food production. The total effects of land-use dynamics on a global level will therefore be different.

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

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

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

The GLOBIO implementation of stable areas with suitable environmental conditions shows relatively little variation in the calculated parameters. More variation can be found in different climate models that give future environmental conditions, and in the sensitivity of the climate system to rising atmospheric CO_2-eq concentrations. With extreme values for climate sensitivity and assuming linear responses of biodiversity, a biodiversity response from -1.8% to -4.5% is estimated (see Table 3.4.1). This range in values is comparable to the values found for the different crop types and land allocation, discussed above.

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

Including species-richness in the MSA indicator
An important characteristic of the MSA approach is the integration of different impacts in one and the same indicator, and the possibility to aggregate the biodiversity values over countries and regions. This allows comparing and balancing different pressures and time scales. As a consequence of this approach, MSA is not sensitive to all aspects of biodiversity. It is not sensitive to the species richness of different biomes, and all different ecosystem types (whether species rich or poor) are treated equally.
To explore the possibilities of including species richness in the indicator, the usual are weighing was complemented by species weighing. This was done by using species richness numbers compiled for each distinguished eco-region (64 in total; WWF 2006). The species weighted MSA accentuates species rich regions, such as Latin-America, Africa and parts of Asia. The global biodiversity decline for the OECD baseline is now somewhat larger (-1%). However, the same happens in the 450-ppm option, and the net result hardly differs from the usual MSA.

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

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

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

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

Table 3.4.1 First order sensitivities of varying several assumptions and sources of uncertainty.

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

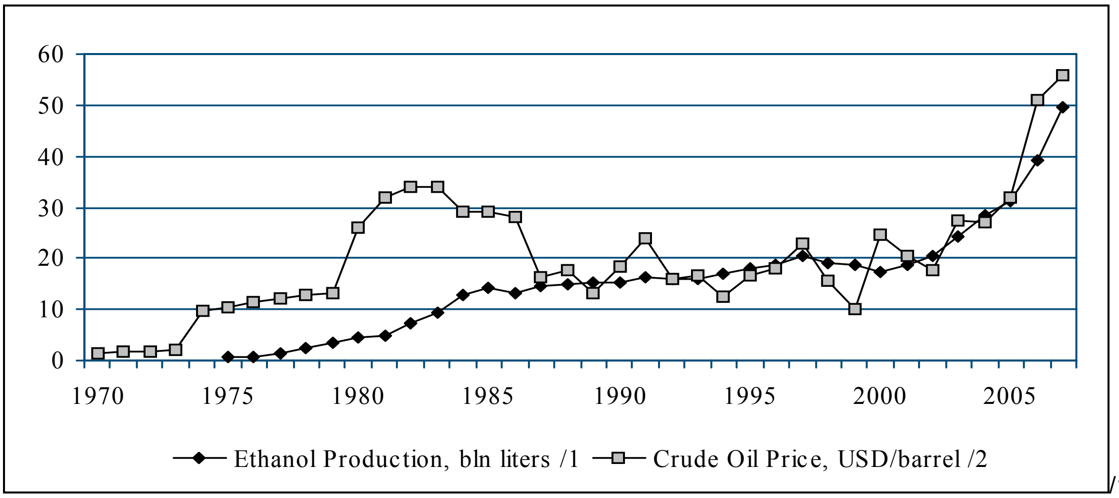
At the top, possible ranges in biodiversity effects of growing bio-energy crops are given, for extreme land-use variants. The GBO2 and OECD 2007 scenarios are taken as a background for the projected area for bio-energy production. Biodiversity values for this area depend on the assumed land-cover (natural,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

3.5 The economic link between food, feed and fuel

World-wide production of biofuels is rapidly growing. World wide production of ethanol tripled from 20 billion litres to 50 billion litres (see, Figure 3.5.1) and world bio-diesel production has grown from 200 million gallons to almost 1000 million gallons in the period 2001-2005. In the European Union in 2004, about 0.4% of the EU cereal and 0.8% of the EU sugar beet production was used for bio-ethanol, and more than 20% of oilseed production was processed into bio-diesel. The growth rate over the previous two years (2002-2004) was 27% and 70% for bio-ethanol and bio-diesel, respectively.

The production of biofuels started after the high oil prices in the seventies which were due to supply restrictions by the OPEC cartel (see, Figure 3.5.1). High oil prices induced innovations that saved oil or replaced oil by cheaper or more reliable substitutes, such as biofuels. World bio-ethanol production grew to about 4 billion gallons in 1985. In the early eighties the oil prices collapsed to their original level and stayed there until the beginning of the new millennium. The level of biofuel production, however, did not collapse but remained almost constant and increased only marginally after 1985. The recent rise in oil prices in combination with environmental concerns lead to the recent biofuel boom.

The only integrated biofuel market in practice is Brazil's cane-based ethanol market. In their ethanol/electricity co-generation system sugar cane becomes a competitive energy provider at petrol prices about US$ 35/bbl (Schmidhuber 2005). The driver for biofuel production in the EU, the USA and Canada is mainly political, including tax exemptions, investment subsidies and obligatory blending of biofuels with fuels derived from mineral oil, while high energy prices further enhance biofuels production and consumption in other countries and regions. Arguments for biofuel promoting policies are reduction of greenhouse gas emissions in the light of climate change, diversification of sources of energy, improvement of energy security and a decreased dependency on unstable oil suppliers, benefits to agriculture and rural areas, etc.



/1 F.O. Licht (2007).
/2 Nominal prices. Saudi-Arabian Light-34°API.
Source: http://www.eia.doe.gov/emeu/aer/txt/ptb1107.html (17.07.2007)

Figure 3.5.1 World fuel ethanol production and crude oil prices: 1970 – 2005

The growing integration of food and energy markets increases the ability to channel agricultural supply either to food, feed or fuel processing. If this trend continues one can expect that the agricultural raw material price implied by future energy prices will either act as a ceiling – as long as it is profitable to use bio-fuel crops for energy production – or, if agricultural prices go above such threshold, demand for bio-based products for energy production will become negligible. This basic price transmission from energy to agricultural prices depends on various factors, which are (a) conversion technologies and costs; (b) carbon prices; (c) legislation, e.g. mandatory blending obligations and (d) economic incentives such as subsidies or tax exemptions.

Until now biofuels have been produced by processing agricultural crops using available technologies. These so called first-generation biofuels can be used in low percentage blends with conventional fuels in most vehicles and can be distributed through existing infrastructure. Advanced conversion technologies are needed for a second generation of biofuels. The second generation will use a wider range of biomass resources-agriculture, forestry and waste materials- and promise to achieve higher reductions in greenhouse gas emissions and the costs of fuel production (Smeets et al., 2006 and Hoogwijk et al., 2005).

Given the current policy developments and the availability of just first generation biofuels an increased biofuel production either due to ‘pure’ market forces and/or ‘policy’ might has significant impacts on agricultural markets, including world prices, production, trade flow, and land use. The fact that demand elasticities for energy are much higher compared to most food products also contributed to the strong dynamics agri-food market shows during recent years. Linkages between food and energy production include the competition for land, but also for other production inputs. The effect of an increasing supply of by-products of biofuel production such as oil cake and gluten feed also affect animal production for instance.

Furthermore, the biofuel boom raised concerns such as whether biofuels would hurt poor people by increasing food prices or whether it would lead to loss in biodiversity due to increased land use. All these implications are not well understood and recent studies tried to address these issues.

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

EU-RURALIS is focused on the EU-situation and assesses the biofuel policy. First results are published in (Wageningen UR and Netherlands Environmental Assessment Agency, 2007). Within the EU-RURALIS project (Version II) the GTAP model has been extended to analyze world wide expansion in the production of biofuels. The reference scenario assumes no mandatory blending for biofuel use. However it is important to notice that due to changes in relative prices (biofuel crops vs. fossil fuel) the use of biofuels also changes under the reference scenario even without a mandatory blending. The consequences of the EU biofuel directive on land demand and agricultural production within the EU and outside Europe are illustrated in Figure 3.5.2.

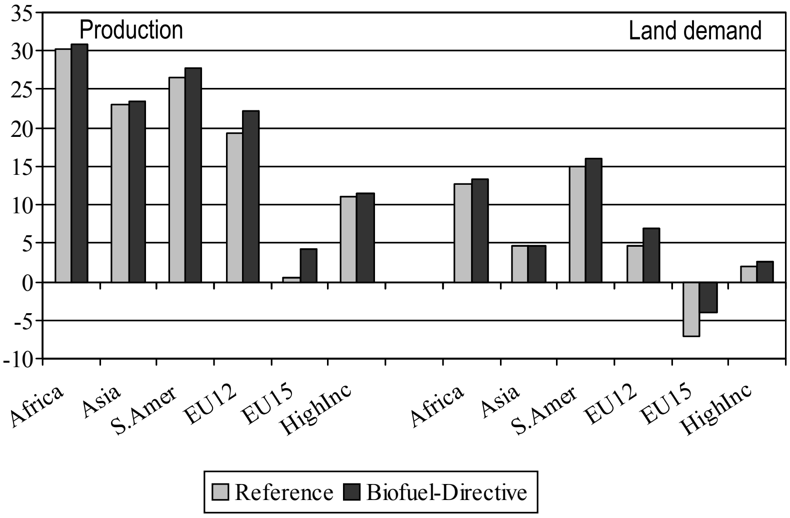


Figure 3.5.2 Impact of EU Biofuel Directive on Agricultural Land Demand and Production, 2010, change in percent relative to initial situation (2001)

The EU-biofuel directive has a strong impact on the agricultural production and land use not only in Europe (EU15 and EU12) but also to countries outside Europe. Especially in Central and South America the agricultural production increases due to the additional demand for biofuel crops in Europe. To meet the ambitious future targets large scale production of biofuel crops in Europe will be necessary. In the Biofuel-Directive scenario the demand for biofuel crops used in the petrol sector will be 7.3 billion USD (in 2001 values) under the minimum blending of 5.75%. Around 42% of these inputs will be produced domestically and 58% of biofuel crops used in the petrol sector will come from imports (see, Figure 3.5.3). Under the Reference scenario where mandatory blending is not enforced the use of biofuel crops is much lower; only 2.5 billion USD

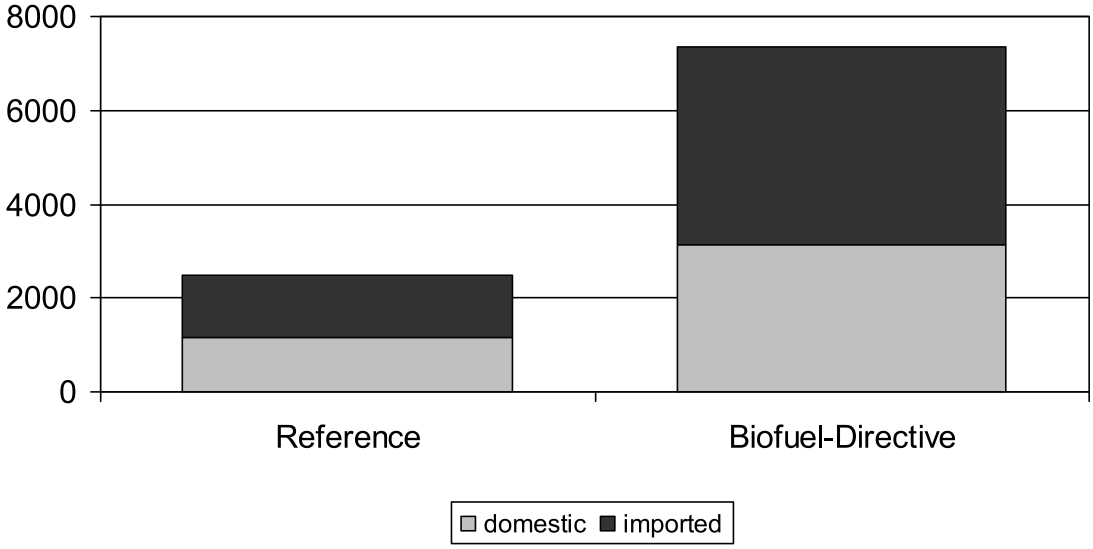


Figure 3.5.3 Biofuel Crops Used in the EU-27 (in Mill USD, 2001), 2010

Under the Reference scenario without mandatory blending the share in imported biofuel crops used for biofuel production is 53.5%. If the Biofuel Directive is enforced, imports in biofuel crops strongly increase.

The enhanced demand for biofuel crops in the EU under the Biofuel-Directive scenario leads to an increase in world prices for these products and hence to a decline in the profitability in fuel production compared to crude oil. Growing prices for bio-fuel crops reduces the use of agricultural products in fuel production outside the EU. However, the increase in biofuel crop demand in the EU over-compensates the decline in non EU countries and at global level the use of biofuel crops for fuel production increases under the Biofuel directive scenario. A good indicator for this development is the decline in crude oil price under the Biofuel Directive scenario compared with reference scenario. Given the assumption that biofuels lead to lower CO2 emissions than fossil fuel, the decline in the world oil price also indicates that the EU biofuel directive leads to less CO2 emission on the global level.

3.6 Greenhouse gas balances

Reducing greenhouse gas (GHG) emissions is a major driver for using biomass for energy and materials and many studies deal with GHG balances of biomass production and uses. Here, a number of review studies that analysed a large number of GHG balances of biofuels and their main results are discussed. (Larson, 2006; Quirin et al., 2004, WWI, 2006; JRC, 2007). It should be noted, however, that these studies are not assessed on the GHG balances of various biomass sources. In addition it is remarked that only very few studies on biofuel production in developing countries exist.

The main results of these reviews is that in most biofuel chains turn out to reduce net GHG emission compared to their fossil counter-parts on a life-cycle basis with few exception found in the studies reviewed. The net results on GHG emission reduction in the analyzed studies, however vary broadly due to variations in methods and input data (e.g. rate of N_2O emissions) and due to differences in the performance of different biofuel chains (see also Figure 3.6.1) Most important aspects determining the GHG balances due to differences in biofuel chains are:
- Productivity of crop production (including fertilizer use)
- Efficiency of biomass conversion (including biomass use for process energy)
- Use of by-products and residues (allocation of the emissions)
- Land use changes (leading to changes in the carbon content)

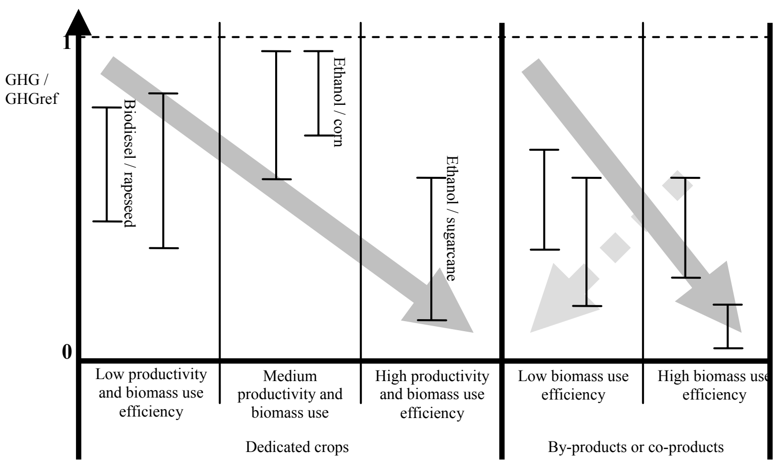


Figure 3.6.1 GHG effectiveness of different bioenergy systems. (B. Schlamadinger, Johanneum research, personal communication)

Productivity of crop production
Crop yields are an important factor for the evaluation of GHG balances, especially if compared on a per hectare basis; see for example Figure 3.6.2 and Table 3.6.1. Clearly crop yields depend on the type of crop produced and perennial crops often have higher yields than annual grain and seed crops. Moreover, crop yields and GHG balances also depend on the agricultural

input - e.g. diesel and fertilizer, which are typically higher for conventional agricultural crops than for perennial lignocellulosic crops. It should be noted, that crop yields also depends on climatic conditions as well as on soil quality and that, therefore, GHG balances are location dependent.

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

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

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

Another important issue is the use of residues from agriculture, forestry and processing for bioenergy production. In this case, GHG emission of producing these residues might be allocated to the main product of which the biomass is a residue of. The residue then comes without allocated GHG emissions and the use of the residue then leads to a large net reduction of GHG emissions. However, it has to be taken into account that these residues often have alternative uses – if not used for energy – and that either these uses have to be accounted for in GHG balances or GHG emissions of production needs to be allocated to the residues. This leads to lower GHG emission reductions of the use of the residue.

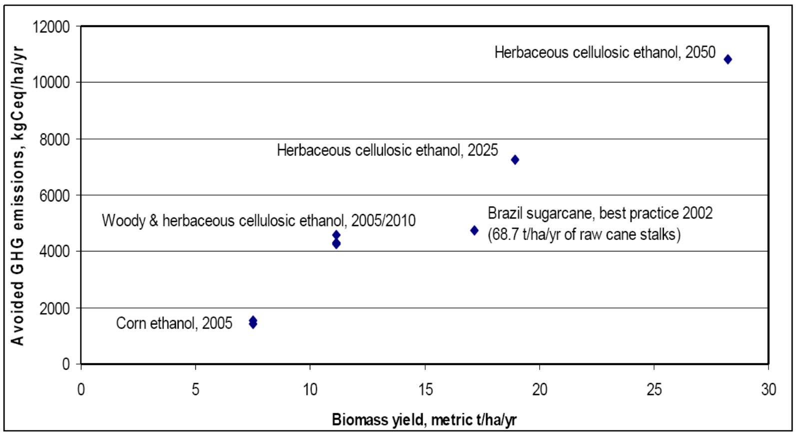


Figure 3.6.2 Avoided GHG emissions per hectare per year as a function of biomass yield for different routes to bioethanol production. (Larson et al., 2006)

Table 3.6.1 Estimated change in life-cycle greenhouse Gas emissions per km travelled by replacing gasoline with ethanol from different feedstock (WWI, 2006)

Feedstock (country or other specifics, where available)	**Emissions Change (percent)**	**Source**	**Feedstock (country or other specifics, where available)**	**Emissions Change (percent)**	**Source**
Corn			**Wheat**		
E10 (U.S.)	-1	M. Wang et al. (1999)	E100	-19	European Comm. (1994)
E10 (China)	-3.9	M. Wang et al. (2005)	E100	-32 to -35	Levy (1993)
E85 (U.S.)	-14 to -19	M. Wang et al. (1999)	E100	-45	Wuppertal (2005)
E85 (China)	-25	G. Wang et al. (2005)	E100	-47	Gover et al. (1996)
E90 (U.S., 2010)	*+3.3*	Delucchi (2005)	E100 (UK)	-47	Armstrong et al. (2002)
E95 (U.S., 1999)	-19 to -25	M. Wang et al. (1999)	**Sugar Beet**		
E100	-13	Farrell et al. (2006)	E100	-35 to -56	Levy (1993)
E100	-21	Marland et al. (1991)	E100 (N. France)	-35 to -56	Armstrong et al. (2002)
E100 (wet-milled)	-25	M. Wang (2001)	E100	-41	GM et al. (2002)
E100	-30 to -33	Levy (1993)	E100	-50	European Comm. (1994)
E100 (dry-milled)	-32	M.Wang (2001)	E100	-56	Wuppertal (2005)
E100	-38	Levelton (2000)	**Molasses**		
Sugar Cane (Brazil)	-87 to -96	Macedo et al. (2004)	E10 (Australia)	-1 to -3	Beer et al. (2001)
Wheat residue	-57	Levelton (2000)	E85 (Australia)	-24 to -51	Beer et al. (2001)
Corn residue	-61	Levelton (2000)	**Grass**		
Hay	-68	Levelton (2000)		-37.2	Delucchi (2005)
Crop residue	-82	GM et al. (2002)		-66 to -71	GM et al. (2001)
Wood	-51	GM et al. (2002)		-71	Levelton (2000)
Poplar tree	-107	Wang (2001)		-73	Wang (2001)
Waste wood (Australia)	-81	Beer et al. (2001)			

Land use changes

GHG emissions and sequestration that are due to land use changes can play a major role in the overall GHG balance of biofuels (WWI, 2006), but are not accounted for in many LCA studies regarding GHG emissions of bio-energy chains. Research on GHG balances of for example palm oil has shown that changing forests or wetland to biomass plantations in general has a very negative impact on GHG emissions leading to net GHG emissions of the biomass chain. On the other hand, using degraded land and planting palm oil can lead to a net sequestration of carbon. (Wicke et al., 2007) Carbon losses or sequestration from land use change are, however, a singular event, while producing bioenergy on the land can be in principle unlimited in time. The GHG balance, therefore, depends also strongly on the time period the carbon changes from land use changes are allocated, too.

4 Discussion

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

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

4.1 Issues covered in quantitative analyses in Chapter 3

Improvement agricultural management
Yields for food and energy crops as well as animal production system are a key issue in determining technical biomass potentials. For example (Smeets et al., 2007) has shown that depending on different agricultural management systems that are medium to highly efficient, the potentials for bioenergy crops vary from 200-1400 EJ/yr. Modelling in IMAGE has shown that increasing yield levels of food and energy crops by about 12.5% and bringing 2050 technology levels in developing countries close to current Western European levels, leads to an increase of 40-60% of biomass potentials in the DV-2 scenario, respectively. For comparison, global average increase in cereal yields between 1961 and 1998 was about 2.2%/yr (FAOSTAT).[5] An important aspect of improving agricultural management is the rate of deployment of more efficient agricultural management practices in the developing countries, which itself depends on many factors that are often included in scenario analysis, such as socio-economic developments, policies, resource endowment, infrastructure, power, etc

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

Perennial lignocellulosic crops, such as herbaceous and woody crops usually have higher total energy yields than annual starch, sugar and oilseed crops. The amount of biofuel that can be gained from these annual crops via 1st generation processes from 1 hectare is typically lower than the amount of biofuel that can be gained from lignocellulosic crops via 2nd generation processes. However, once 2nd generation technologies become commercially available, also lignocellulosic agricultural residues of annual starch, sugar and oilseed crops can be used for biofuel production. Another advantage of lignocellulosic crops is the fact that they are usually better suited to marginal lands (i.e. lands on which crop yields are very low) than annual crops. However, some of these marginal lands might not be suited to biomass production at all. It

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

should be noted, that some perennial crops that are suited to the production of 1st generation biofuels such as sugar cane and palm oil have rather high yields, too.

Bio-energy demand versus supply
Typically, supply and demand of biomass are investigated in separate models leading to estimates of geographical - what can be produced given land availability - and economic – what will be produced and used from an economic point of view - biomass potentials. Most studies on geographical biomass supply estimate only total amounts of available biomass, while some also analyse cost-supply curves of biomass. Dynamic adaptations of biomass supply to demand are, however, not considered in recent studies. Comparing scenario analysis of available biomass supplies with bioenergy demands shows that demands are typically lower than supply, even though the gap depends on the costs of biomass as well as on the assumption on global energy demand. In section 3.2, the global demand for biomass for the use for energy as modelled with TIMER is about 15-20% of the possible supply (section 3.2.1 and Appendix I). However, no result of integrated modelling supply and demand is available considering price effects. It should be noted that energy demand depends on cost-supply curves of biomass as well as learning in energy conversion, see below.

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

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

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

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

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

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

4.2 Issues <u>not</u> covered in the quantitative analyses in Chapter 3

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

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

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

Costs of biomass supply
The costs of biomass supplies are important for the amount of biomass that can be used economically, i.e. for the bioenergy demand. However, in energy demand models either static costs are used or cost-supply curves based on the availability of land after reserving land for other function. (Hoogwijk et al., 2005) analysed using the latter method, the amount of energy crops available at prices below 2 Euro/GJ which is about the price of coal. This amount is about

30-40% lower than the overall technical potentials. Given the nature of biomass supply curves used, no price effects of competition between resources (biomass for materials, food, agricultural land, water, nature conservation) are taken into account in the cost-supply curves that determine energy demands, even though they are relevant for modelling.

Use of by-products from agriculture and forestry

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

Water use efficiency of crops

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

Climate change

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

Alternative protein chains

The production of proteins from animal farming uses large amounts of land and other resources. Life cycle assessment showed that a transition from animal to plant protein might result in a 3-4 fold lower requirement of agricultural land and about a 30-40 fold lower water use (Aiking et al., 2006). The land and water resources that could be made available by such a transition could then be (partly) used for biomass production and for relieving the pressure on biodiversity. The influence of changing protein sources for human consumption on biomass potentials could not be quantified within this study and has not been studied in the reviewed biomass potentials studies, but might be potentially large. An area of 25 million hectares of soy would yield an amount of protein equivalent to livestock presently fed by 400 million hectares of feed crops (300 Mha grains plus 100 Mha oilseeds), thus setting 375 Mha free[6] (Aiking et al., 2006). Changing protein sources requires technological change as well as a change of consumption patterns. Present trends, however, suggest meat demand to be increasing, rather than decreasing.

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

Demand for biomaterials
Wood and fibre products (pulp, timber, boards, etc.) are the largest group of biomaterials that are currently produced. In studies considering all types of biomass resource, the demand for wood products is included, i.e. the wood products demand is subtracted from the future biomass potentials. (Smeets et al., 2007) estimated the difference between high and low future demands for wood products in 2050 to be about 30 EJ/yr. Chemicals and other biomaterials might become another important area for biomaterial use and are usually not included in biomass potentials estimates. However, demands for biomaterials are comparatively low[7] and do not exclude the use of biomass for energy as cascading strategies, i.e. first using biomass for food, feed, materials and then converting organic wastes to energy, can be applied.

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

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

4.3 Overview key uncertainties

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

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

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

Table ES.2 Overview of uncertainties and their impact on biomass resource potentials

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

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

[1] Increasing yield levels of food and energy crops by about 12.5% compared to the baseline (half the suggested improvement potential in the International Assessment of Agriculture Science and Technology Development) leads to an increase of about 40% of biomass potentials in the analysis in Section 3. Moreover, bringing 2050 technology levels in developing countries close to current Western European levels leads to an increase of up to 60% of potentials in 2050.
[2] In Section 3, the potential of using severely degraded land (cat. 3 and cat.4 of the GLASOD classification) has been estimated to increase potentials by about 30% (cat.3) and 45% (cat. 3 and 4).
[3] Other main uses that compete with biomass production for water are agricultural, industrial and domestic uses. Excluding areas with a water scarcity of >0.4 and of >0.2, respectively, leads to a decrease of estimated biomass potentials of about 15-25% in the analysis in Section 3. However, due to climate change, in future the number of regions with water scarcity will increase and competition for water will become more important.
[4] Reserving nature reserves in areas designated to become nature reserves under the Sustainability First scenario of the Global Environmental Outlook of the UNEP leads to a reduction of up to 25% of biomass potentials.
[5] The economic biomass potentials based on energy demand modelling is much smaller than the possible technical biomass supply. Starting from a biomass cost-supply curves with a maximum supply of 700 EJ/yr in 2050, the energy demand at carbon taxes of 0-300 €/tC is only about 15-20% of the possible supply, i.e. the economic potential is 80-85% lower than possible supply.

4.4 Summary: what we know and don't know

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

1. *Are biomass potentials sufficient to supply a large part of future energy demands?* [8]
   In principle, biomass potentials are likely to be sufficient to allow biomass to play a significant role in the global energy supply system. Under the assumption that food demands of future population are met, most recent studies estimate global biomass potentials of 300 to 800 EJ/yr in 2050 for various scenario conditions. Our own analysis showed that under negative circumstances concerning land availability - i.e. excluding large areas for nature protection, mildly to strong water scarce areas and mildly and severely degraded land from biomass production – only about 80 EJ/yr from energy crops might be available, while an additional amount of about 80 EJ/yr from residues and an additional amount about 60-100 EJ/yr of surplus forest growth is likely to be available. At the same time, scenario analyses predict a global primary energy use of about 600 – 1040 EJ/yr. (WEA, 2000) Energy demand models that calculate the amount of biomass used if energy demands are supplied cost-efficiently at different carbon tax regimes, estimate that in 2050 about 50-250 EJ/yr of biomass are used; a range that is significantly lower than the estimated supply potential. For determining future economic potentials of bioenergy more exactly, however, an advanced integration of demand models with cost-supply curves of biomass and extended knowledge about technological learning in energy conversion technologies would be necessary.

2. *What drives the economic competitive use of bioenergy and materials?*
   Most important in the economic part in the discussion around bioenergy is the fact that feedstock crops such as cereals, oilseeds or sugar cane are in direct competition with food on the consumption side. For biomass such as willow or switchgrass, this competition is less stringent, but also in this case biomass production is in direct competition for scarce resources, especially land. Changes in relative prices between different crops and between different energy sources, i.e. energy crop prices versus fossil energy prices, are the key drivers in future use of biomass. The economic analysis of biofuel use clearly shows that apart from direct policy measures, e.g. mandatory blending commitments, this price ratio is the most significant driver in the use of biofuels. Any analysis of biofuel potentials which also takes economics into account must consider this key element. However, the dynamics are also important, because shifts in relative prices also trigger investments and technical progress in the biofuel sector which lowers in the long-term production costs and increases the long-term profitability of biofuel production.

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

4. *What role might degraded lands play in biomass production?*
   Another question in determining future biomass potentials is whether degraded lands - of which productive capacity has declined temporary or permanent - can be used for biomass production. At this moment the potential of the large area of degraded soils – classified as light and moderately degraded and covering about 10% of the total land area – to contribute to the production of biomass is not yet clearly assessed. This is because of the unknown impact of two possible drawbacks: firstly the large efforts and long time period required for the reclamation of degraded land and secondly the low productivity levels of these soils. In the integration analysis it has been shown that using severely degraded land would increase biomass potentials from energy crops by about 30-45%, assumed that in principle it would be possible. However, using severely degraded land for annual crop production might

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[8] In the assessment of the German Advisory Council on Global Change that assumes a very limited availability of land due to nature protection and high food consumptions with at the same time very low crop yields, only about 70 EJ from residues and about 40 EJ from energy crops are estimated to be available. (WBGU, 2003)

require large investments and many attempts for reclaiming degraded land for food production have failed. Other attempts with e.g. reforestation and agro forestry might be more promising for biomass production and some projects in the past on e.g. saline soils have been successful. Further research on the potential of degraded soils for biomass production is needed. Preferably, other mitigation options (carbon storage in soils and vegetation) and adaptation options should be integrated in the research on the potential of degraded soils for biomass production.

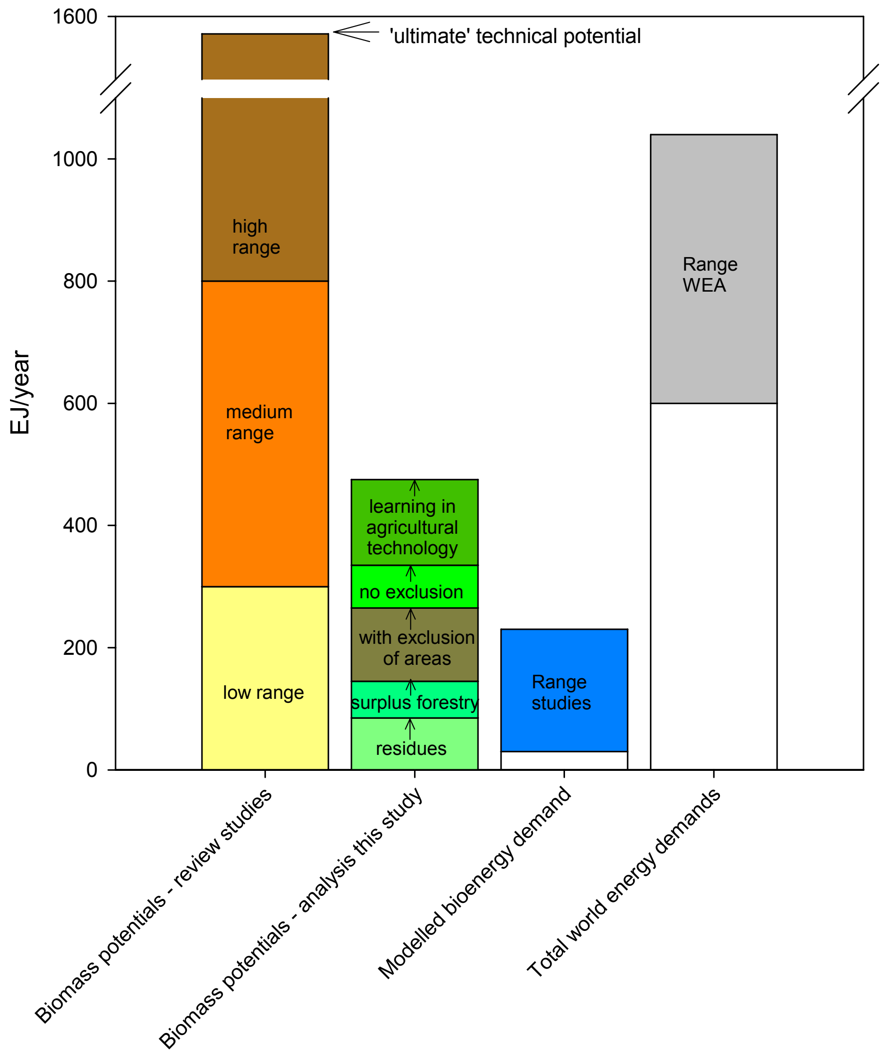

Figure 4.4.1 Comparison of technical biomass potentials with bioenergy demands in 2050. Biomass potentials as analysed in this study refer to the OECD-baseline scenario of IMAGE. (Exclusion of areas is the exclusion of mildly and severely degraded and water stressed areas as well as the exclusion of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

5. *What determines biomass yields*

It should be noted that the conclusion that future biomass potentials are large enough to play a relevant role in supplying a significant part of future energy demands depends on land availability (see above) and on biomass yields. Ranges of assumptions on land availability in the reviewed literature influence total technical biomass potentials more strongly than the estimated ranges of biomass yields. Biomass yields depend mainly on the development of agricultural management and the choice of crops. First, most recent biomass potentials studies assume that the efficiency of agricultural production improves in the coming decades assuming low to high technology development rates. (For illustration, extreme scenarios that assumed extensive agriculture or high advanced technologies with land-less animal production resulted in estimated future global biomass potentials of about 0 EJ/yr and 1500 EJ/yr, respectively.) Practice, however, shows that deployment of agricultural technologies in developing countries can be a difficult task and implementation strategies need to be studied very well. Second, all estimates of future biomass potentials discussed are based on the use of perennial lignocellulosic biomass in 2050. This necessitates the availability of 2nd generation conversion technologies for the production of biofuels and most chemicals. Perennial lignocellulosic crops have in general higher yields than annual sugar, starch and oilseed crops, while perennial sugar and oil crops (e.g. sugar cane, palm oil) have high yields, too. Calculations in the integration part of this study indicate that potentials for annual biomass crops, i.e. maize, might be very low and not sufficient to provide a large part of energy demands.

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

7. *What is the relation between biodiversity conservation and using bioenergy?*
   Studies that estimate biomass potentials assume in that nature conservation areas are excluded from biomass production. As such estimated biomass potentials consider biodiversity conservation on a base level. Assuming that larger parts of land should not be used for biomass production for reasons of biodiversity conservation, potentials would decrease accordingly.
   In most cases perennial lignocellulosic crops have lower impacts on biodiversity than annual sugar, starch and oilseed crops and are, thus, better suited for combining biodiversity and biomass production. Important open questions in this area are:
   - To what degree potential energy production on a certain piece of land is related to the (potential) biodiversity value of the same piece of land if reserved for nature
   - How to measure biodiversity, realizing different available indicators tell different stories
   - What are the effects of future climate changes on biodiversity (very uncertain) and areas for biomass production (more certain)

8. *What is the effect of biomass use on food prices?*
   Economic analyses indicate clearly that food prices increase with an increased demand for biomass, but the magnitude of this increase is uncertain. In the long term, price increases might accelerate agricultural efficiency leading to larger potentials of food and biomass production and mitigating price increases. For example, OECD and FAO project a price increase of coarse grains prices of about 30% in the short term and about 10-20% in the medium term (2010-2016) compared to 1996 level. At the same time, prices of sugar are projected to increase about 30-40% and then even to decrease compared to 1996 level. (FAO-OECD, 2007) Only part of these projected price developments is due to the increase of biofuel production, while other parts are due to low recent harvests and increasing other demands. This analysis indicates clearly that land, food and energy demand are linked via prices. Thus, a priori not a certain area will be reserved for food production, but economic mechanisms determine the distribution of land uses. For annual crops that are used for the production of 1st generation biofuels, the linkage between food prices and biofuel demands is probably larger than perennial lignocellulosic crops used for 2nd generation biofuel production. This is due to direct competition. However, currently agricultural models do not

include and analyze 2nd generation biofuels and knowledge on the impacts of 2nd generation biofuels on food prices is lacking. Finally, while large amounts of biomass can be used without jeopardizing future global food demands, it should be noted that food availability and affordability are very regional and that this future regional distributions of food and energy supplies are not sufficiently known, yet. Here, further knowledge including the influence of policies and subsidies on food security especially in developing countries is needed.

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

10. *What types of analyses are still needed?*
    This review gives and overview of the most important linkages between the areas of water, food, biodiversity, economic effects, energy demands and biomass potentials. While knowledge and knowledge gaps in these areas have been discussed above an integrated analysis of these areas is still missing. Important issues in such an integrated analysis are:
    - Drivers and barriers in the food-feed-fuel nexus that could be used to refine modelling and scenario analysis of geographical and economic biomass potentials
    - Linkages between the availability and prices of water, the availability and prices of land, the demand for food and feedstock, the demand for energy and between the cost-supply curves of biomass
    - Regional analysis that analyze the relation between food security, biomass potentials, water availability and land use changes on a spatially explicit level
    - Mechanisms of changes and the implications of policy instruments in different parts of the world

5 Conclusions and recommendations

5.1 Main conclusions

Current understanding of the potential contribution of biomass to the future worlds' energy supply indicate that the total supplies could amount from a minimal 100 EJ up to 1500 EJ theoretical potential (compared to some 450 EJ current global primary energy demand). This assessment gave a much more sophisticated view on the factors and biomass resource categories that explain the ranges, which are particularly caused by the way food demand and agricultural management develops and by uncertainties to what extent more marginal and degraded lands may be deployed for biomass production. The potential consists of three main categories of biomass:

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

2. Biomass produced via cropping systems on possible surplus good quality agricultural and pasture lands. This part of the potential biomass supplies is the most significant and can amount up to over 300 EJ for the high level improvement for agricultural efficiency included in the SRES scenario range. It is also a more uncertain category. The key factor determining net availability of land is improvement in efficiency in agriculture and livestock production systems. From a technical perspective, potential efficiency increases are very large seen on a global basis, especially in developing countries as is highlighted in (Smeets et al., 2007). However, the speed at which such improvements may be realized is uncertain and depends on a wide variety of factors which are partly poorly understood and manageable. In particular the economic drivers for such developments require further attention. The lower estimate given in this study based on the OECD scenario results in biomass supplies from energy crops up to 120 EJ (which includes corrections for water scarcity, land degradation and new land claims for nature reserves; see also the third category below). A '*compact agriculture scenario*' (roughly similar to the A1 and B1 SRES scenarios) would add some 140 EJ to that estimated 120 EJ, resulting in a range of 120 – 260 EJ.

3. The use of marginal and degraded lands that are not used for food production. This aspect is addressed in some more detail in this assessment. Although it should be recognized that data quality on such soils is fairly weak, land-use scenarios in this respect are crude and that knowledge to what extent different types of vegetation can be established has seen limited study, some global estimates have been compiled. The potential contribution could add about 70 EJ to the production of energy crops EJ, but this would include a large area where water scarcity provides limitations and soil degradation is more severe. The lower estimate, covering more limited degradation and water scarcity represents the 120 EJ discussed above. This lower estimate also incorporates estimated additional demand for new nature reserves.

The key uncertainties for this category are the extent to which such lands can really be utilized for biomass production from a technical and economic perspective and to what extent nature and biodiversity conservation may conflict with the partial use for biomass harvesting, since marginal and abandoned lands do represent varying levels of biodiversity. Management, harvest and trade-offs with biodiversity need to be assessed on a regional scale. Another important element is to what extent increased food demand may make it more attractive to use marginal lands for food production in the future and thus compete with bio-energy. Such dynamics can still not be investigated by current modelling tools.

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

Overall (see also figure 4.4.1), this assessment tuned the broad range of estimates of global biomass resource potentials down to a range of minimally 200 EJ up to more than 500 EJ.

Another, perhaps remarkable, result of this assessment (but also confirmed by the recent IPCC 4th assessment report (IPCC, 2007, Chapter 11) is that current energy scenarios which include GHG mitigation strategies following IPCC guidelines, indicate that the demand for bio-energy until 2050 could in fact be limited compared to the potential biomass supplies, because various other options are more competitive in terms of specific mitigation costs. This may in particular be true for the use of biomass use for power generation because other alternatives (such as wind energy, fossils with CCS and nuclear energy) are more attractive at marginal biomass costs above ca 3 US$/GJ. The estimated demand for primary biomass reported in this assessment (based on MARKAL and TIMER model results) amounts maximally ca 150 EJ, with ranges in other models of about 50-250 EJ. This is basically within the range of the indicated biomass resource potentials. In particular, the residues and wastes can cover a very significant part of the demand to start with. Especially production of transport fuels (based on lignocellulosic biomass via 2nd generation technologies) is expected to play a dominating role on medium term. Biomass use for materials and feedstock adds to the demand, but is a minor factor in total demand based on most current model results, although this area has still received limited attention. It should be noted though, that the indications given by the IPCC, MARKAL and TIMER are based on relative cost effectiveness (e.g. costs per ton of CO2 emission avoided). Other drivers, such as energy security and rural development could result in sustained policy support in particular for biofuels. This may increase demand for biomass considerably. In addition, the total energy demand is uncertain and in the higher projections, biomass demand may rise well over the indicated 150 EJ.

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

The key studies that provided an important basis for the potential estimates mentioned are (Hoogwijk et al., 2005) and (Smeets et al., 2007). Given that those are among the most recent studies available and that in particular the Hoogwijk study already incorporated various limitations with respect to nature areas, low productive areas, etc., these played an important role. The IPCC SRES scenarios used in the Hoogwijk analyses were used as a basis for this assessment as well, varying agricultural efficiency and using the base land cover simulations of the IMAGE model. This assessment has provided several corrections of the available results to date, especially with respect to water availability, soil quality and protected areas (which were excluded from the potentials for biomass production). These are significant and led to corrections to earlier estimates of the resource potentials as argued above. Prime factors that influence that size of the potential are listed in table 5.2.1.

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

5.2 Key uncertainties and weak spots or gaps in available knowledge

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

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

Issue/effect	Importance	Recommended activities to reduce uncertainties
Supply potential of biomass		
Improvement agricultural management	***	Research to better understand how efficiency and livestock can be increased in a sustainable manner and for different settings. Insight in development pathways and feasible rates of improvement need to be integrated in modelling frameworks, Improved insights in pre-conditions for improvements can provide a basis for targeted policies.
Choice of crops	***	There are clear recommendations on the importance of lignocellulosic biomass production systems for different settings. Under certain conditions, sugar cane and palmoil could still be feasible options on longer term as well. Much more market experience with such production systems needed in different settings, including degraded and marginal lands, intercropping schemes (e.g. agro-forestry) and management of grasslands. The latter is an important land-use category on which current understanding and data needs improvement.
Food demand	***	Increases in food demand beyond the base scenarios (e.g. up to 9 billion people in 2050) that were the focus in this study will strongly affect possibilities for bio-energy. Vice versa, limited population growth will mean the opposite.
Use of degraded land	***	Represents a significant share of possible biomass resource supplies. Experiences with recultivation and knowledge on these lands (that represent a wide diversity of settings) are limited so far. More research is required to assess the cause of marginality and degradation and the perspectives for taking the land into cultivation. Research and demonstration activities required to understand the economic and practical feasibility of using degraded/marginal land is needed. This land-use category also requires attention (e.g. via better databases) in modelling efforts.
Competition for water	***	Increased water demand for conventional agriculture, domestic and industrial use is a concern in various world regions, with agriculture being by far the most important sector in this respect. This assessment provided a first order insight in how (energy) crop production potentials may be constrained by water availability, which is significant already in some regions and will increase in the future. Constraints in water supplies and sustainable management need ultimately to be studied at water basins scale, in interaction with local scales.
Use of agricultural /forestry by-products	**	Residues are an important resource category. The net availability for energy purposes can in the future in particular be affected negatively by competing applications (e.g. biomaterials and traditional biomass use). Their net availability can be improved by better infrastructure and logistics.

Issue/effect	Importance	Recommended activities to reduce uncertainties
		Key areas for research and sustainable management are maintaining sound organic matter levels in soils and nutrient balances. To some extent (especially for residues in tropical regions) more research and field experience to determine such levels is desired.
Protected area expansion	**	Increased ambition levels for nature reserves on global scale can have a significant impact on net land availability for biomass production. Land exclusion assumptions in the available studies, however, seem to overlap with the potential future land claims for nature and further modelling work and improved databases are desired. Furthermore, more insights are desired in how land use planning including new bio-energy crops can maximize biodiversity benefits. Evaluating biodiversity impacts on regional level is still a field under scientific development and more fundamental work is needed in this arena.
Water use efficiency	**	See above under competition for water. An important factor in the equation is improvement of water use efficiency in both current agriculture (that could be achieved through efficient management adapted to the local production situation, increasing resource use efficiency) and of biomass production itself.. Technical improvement potentials are considerable compared to current average practice. This suggests that for various areas water management is prime design parameter for sustainable biomass production and land-use management. This area deserves considerable further research efforts, preferably linked to field experience and the socio-economic environment.
Climate change	**	The impact of climate change on agricultural production and productivity of lands could be significant, but exact effects are also uncertain. Effective mitigation strategies, of which large scale bio-energy deployment could be a significant element, will limit the influence of this factor. At this stage, this is still the objective of the governments that have signed the Kyoto Protocol. Varying reported effects of climate change on natural systems and their biodiversity deserve further attention. Especially variation due to using different indicators and modelling concepts should be better explained. This will influence the balance between land-use dynamics and avoided climate change effects. Furthermore, although agriculture may face serious barriers due to climate change, this may also enhance the need for alternative adaptation measures to avoid soil losses and maintain vegetation covers. Biomass production (again especially via perennial systems) may than play a role as adaptation measure. Such strategies (under different climate change scenarios) are so for hardly studied and deserve further attention in future research efforts and scenario analyses.
Alternative protein chains	**	See above under food demand. Possible but very uncertain reversal of current diet trends, i.e. introduction of more novel plant protein products (as alternative for meat) could on the longer term strongly reduce land and water demand for food. Such options and the feasibility in terms of implementation are however insufficiently studied. Further work in this area is recommended.
Demand for biomaterials	*	Demand for biomass to produce biomaterials (both conventional as building material as new ones as bulk bio-based chemicals and plastics) can be a significant factor, but is limited due to market size (compared to demand for energy carriers). Furthermore, biomaterials will also end up as (organic) waste material later in their lifecycle, indirectly adding to increased availability of organic wastes. In many cases this 'cascaded use' of biomass increases the net mitigation effect of biomass use. For some biomaterial markets specific cropping and plantation systems may be required due to demands of the biomass composition. Biomaterials are so far poorly integrated as a factor in energy models and as mitigation option. This can be improved in further work to understand the interactions between different flows and markets better (also in macro-economic terms).
GHG balances of biomass chains	*	The net GHG performance of biomass production systems is not identified as a limiting factor for the potential, provided perennial cropping systems are considered. Also, striving for biomass production that is similar or better than previous land use (e.g. grasslands that remain grasslands or trees

Issue/effect	Importance	Recommended activities to reduce uncertainties
		that replace annual crops) generally improves the overall carbon balance. This can also be true for replanting of degraded lands. The key factor in the net carbon balance is leakage. Avoiding leakage is directly related to increased efficiency in agriculture and livestock and net carbon impacts of biomass production should include this dimension. Such dynamics should ideally also be incorporated in future modelling exercises.
Demand potential of biomass		
Bio-energy demand versus supply	**	The data on potential biomass demand in future energy scenarios reported in this study hint that biomass demand may in fact be lower than the biomass supplies that could be generated in baseline scenario's used (as 'OECD Baseline'). At ambitious levels of climate change abatement, the key demand factor is likely to be the use of biomass for transport fuels due to the very few alternatives available for oil and reducing CO2 emissions in the transport sector. Nevertheless, long term energy demand projections are also characterized by considerable variability (especially caused by GDP and population growth and the rate of deployment of energy efficiency measures at large). Demand for example transport fuels could therefore also be significantly higher than projected in this report and this could be further enhanced when policies target increased energy security and rural development as other priorities that are likely to favour biomass and biofuels. It is recommended to incorporate (dynamic) biomass supply projections and a more diverse portfolio of conversion options (e.g. including hydrogen production from biomass and combined with CCS) in current models to obtain more coherent analyses and scenarios.
Cost of biomass supply	**	The costs of biomass supplies are influenced by the degree of land-use competition, availability of (different) land (classes) and optimisation (learning) in cropping and supply systems. The latter is still relatively poorly studied and incorporated in scenario's and (energy and economic) models, which can be improved. Nevertheless, the variability of biomass production costs seems far less than that of oil or natural gas, so uncertainties in this respect are relatively limited.
Learning in energy conversion	**	See remarks on energy models and costs of biomass supply; better insights in development potentials of key technologies (2nd generation systems) and biomass supplies will improve the quality of scenario results with respect to the relative role of biomass for energy (and materials).
Market mechanism food-feed-fuel	**	To date, limited modelling efforts are available to fully interlink macro-economic/market models with biomass potential studies, especially when lignocellulosic biomass is concerned. To date, price dynamics and, longer term, responses of agriculture (in terms of increased land use and/or increased efficiency) are also addressed to a limited extent. Although the long term impacts on actual physical biomass resource potentials may be limited, understanding the economic responses to increased demand for food and bio-energy and how these affect the relative competitiveness of bio-energy compared to other energy supply options is extremely important for defining balanced policy strategies. Linked to this, socio-economic implications (such as impacts on rural income, rural employment) should be further understood.

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

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

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

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

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

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

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

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

5.4 Research needs

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

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

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

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

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

A1.1 Timer-based demand-side energy scenarios

A1.1.1 General

The two curves below depict supply curves of woody biofuels in 2030 (Series 1) and 2050 (Series 2). The increase on the low site of the curve is determined by increasing production costs in low income countries. The decrease on the high side is due to yield increases. Expansion of the curve is both due to yield increases and an increase in abandoned agricultural land.

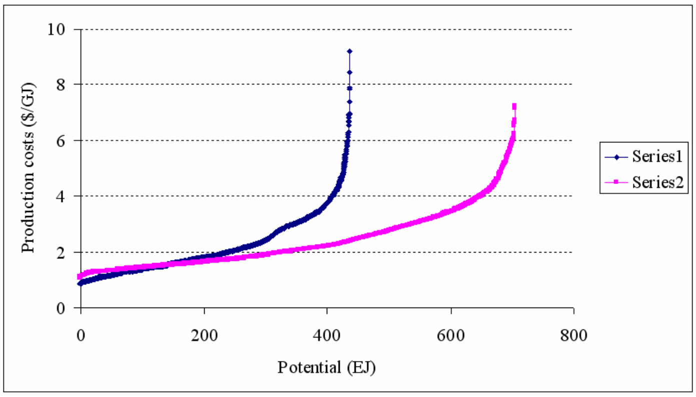


Figure A.1.1 Supply curves of woody biomass in 2030 in TIMER

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

A1.1.2 Overall system

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

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

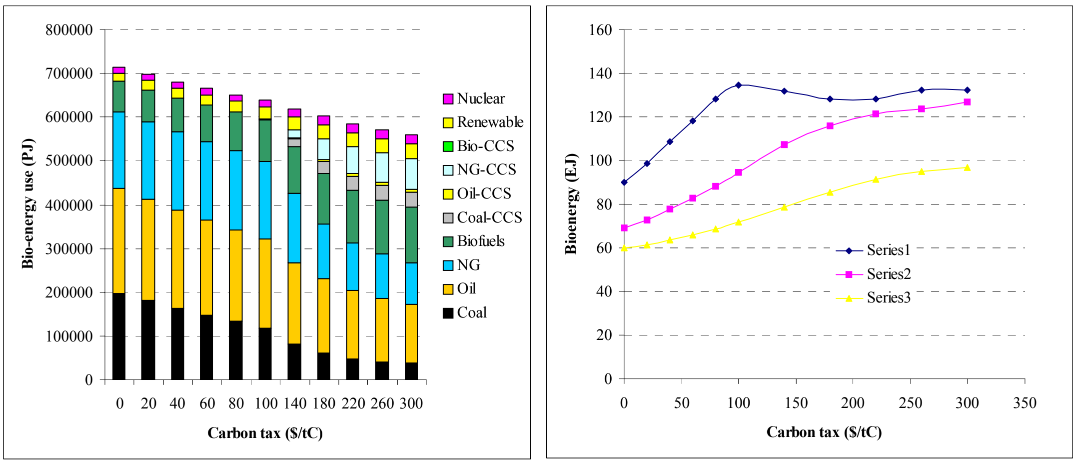


Figure A.1.2 Primary energy use (left) and biofuel use (right) under different carbon tax values.

The next graph shows the use of modern biofuels by sector in the year 2050. At low carbon prices, most biofuels are used in electricity. Biofuel use here increases with increasing prices. However, beyond 100$/tC biofuel use drops in this sector – and a rapid expansion takes place both in transport and industry/non-energy use.

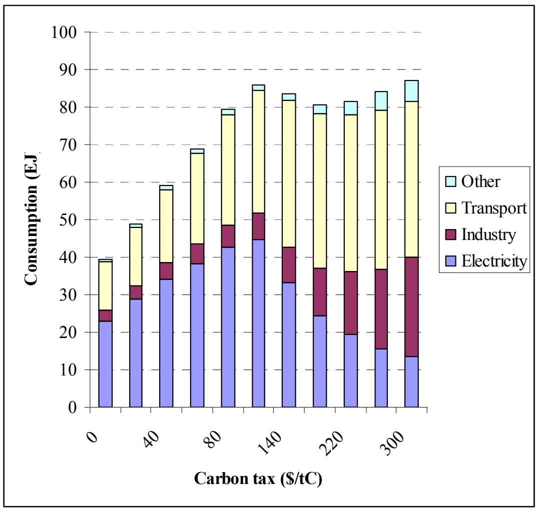


Figure A.1.3 Consumption of biofuel in different sectors as function of the carbon tax.

A1.1.3 Electric power

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

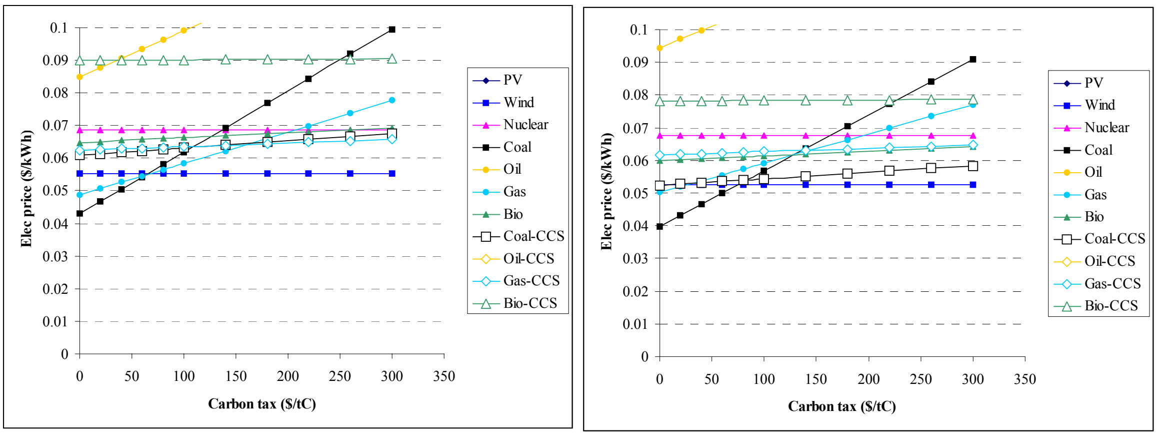


Figure A.1.4 Indication of the costs of producing electricity from different technologies as function of the carbon tax (static representation).

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

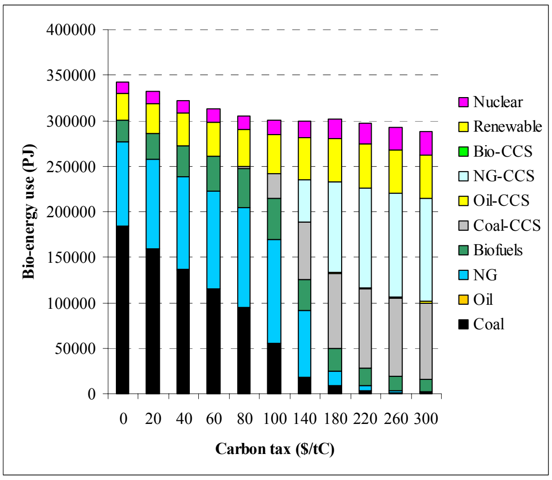
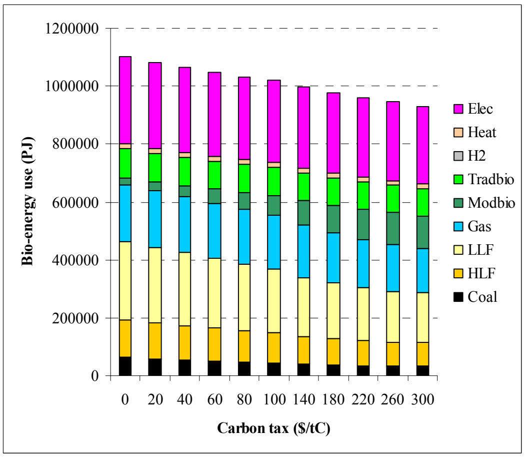


Figure A.1.5 Electricity production by different technologies as function of the value of the carbon tax.

A1.1.4 End use

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



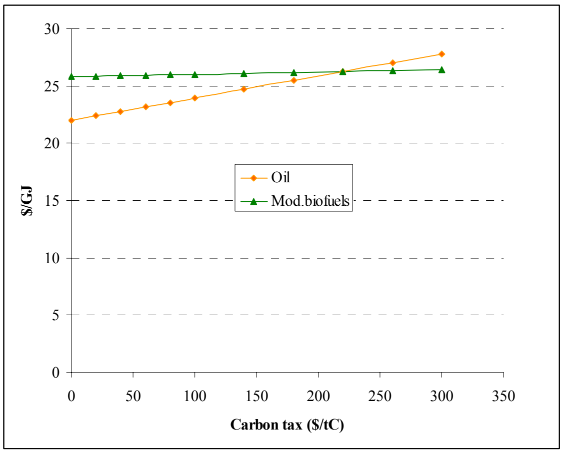


Figure A.1.6 Secondary energy consumption by fuel as function of the value of the carbon tax (left) and the price of oil and modern biofuels in transport (as function of the carbon tax).

A1.2 Markal-based demand-side energy scenarios

A1.2.1 General assumptions

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

Table A1.1 Assumptions scenarios

	Scenario	CO_2 price €/tonne	Biomass potential	Oil/gas price	Comment
1	CM BL (Cascade Mints Baseline)	±10	High	Low	
2	CM CV 100 (Cascade Mints Carbon Value 100 €/tonne)	100	High	Low	
3	CM TP CV	100	High	Low	Assumptions the same as CM CV 100, but with 50% more rapid learning for all the selected and renewable technologies (nuclear, renewables, hydrogen, also gasifiers both coal and biomass-based)
4	TDT DD (Transitie Denk Tank Duurzaam Denktank)	88 as result of 30% CO_2 reduction target	Low (E15+N+CH +ICE)	High(er)	
5	TDT BS (Transitie Denk Tank Biomassa Schaarste)	88 as result of 30% CO_2 reduction target	Lower	High(er)	

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

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

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

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

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

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

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

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

A1.2.2 CM scenarios

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

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

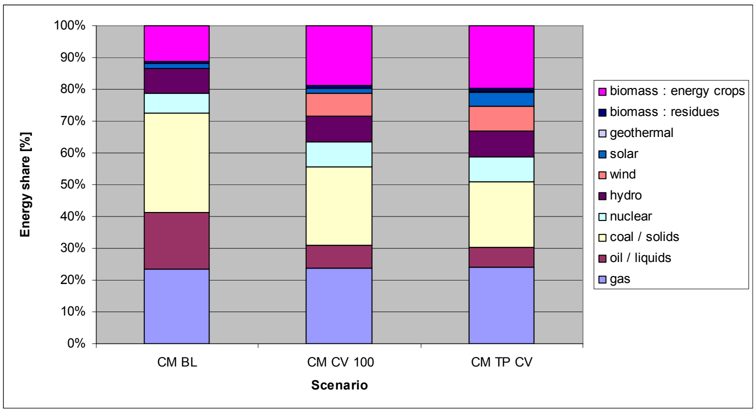


Figure A.1.2 Primary energy share (CM scenarios, 2050)

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

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

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

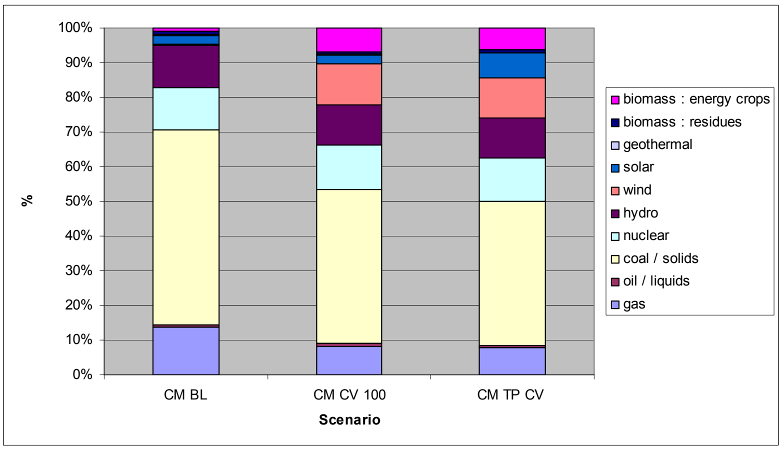


Figure A.1.3 Share of net electricity generation (CM scenarios, 2050)

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

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

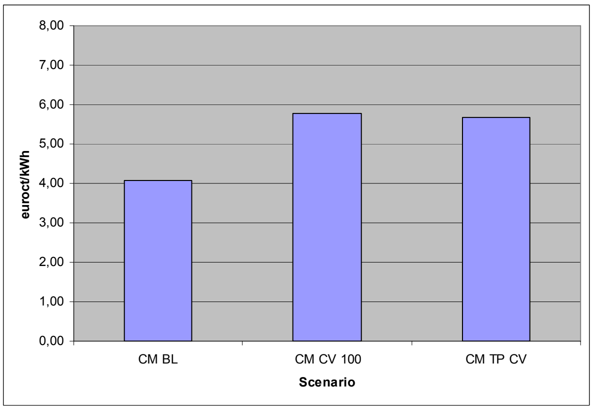
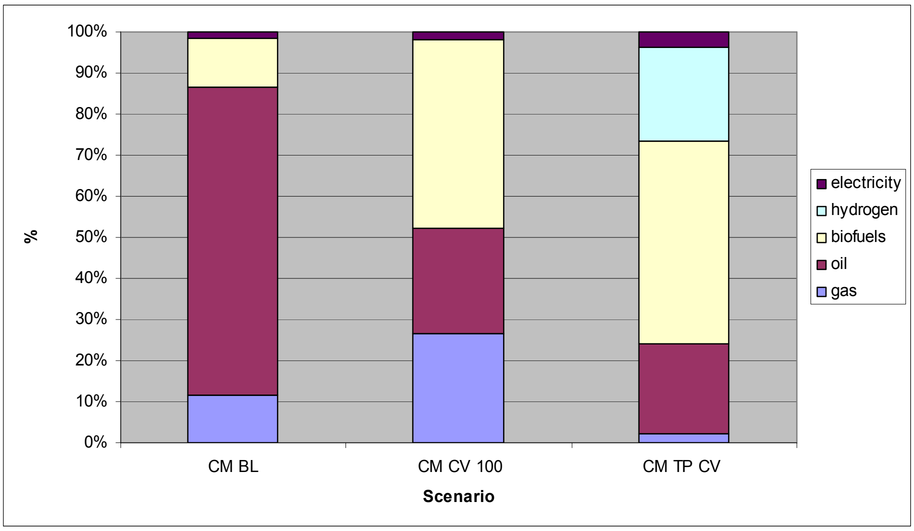


Figure A.1.4 Marginal cost of electricity mix (CM scenarios, 2050)

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

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

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



FigureA.1. 5 Share of final energy demand in transport sector (CM scenarios, 2050)

A1.2.3 TDT scenarios

In the TDT scenarios the biomass potential is the only input parameter that has been changed. The supply of biomass is limited to EU15+N+CH+ICE in the TDT DD scenario, and even more limited in the TDT BS scenario[9]. The biomass costs are the same in both scenarios. Marginal costs for some biomass flows are presented in table A.1.8.

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

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

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

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

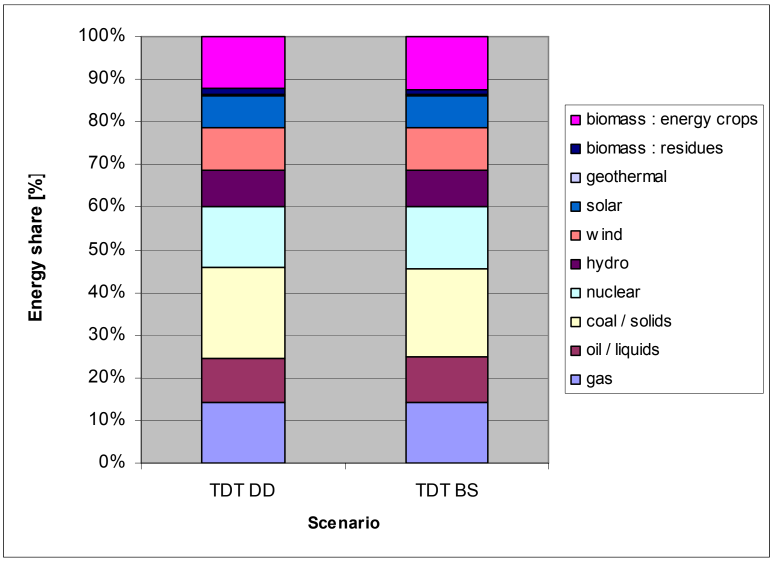


Figure A.1.6 Primary energy share (TDT scenarios, 2050)

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

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

	TDT DD	TDT BS
Gas	11011	10945
Oil / liquids	7814	7958
Coal / solids	16178	15846
Nuclear	11016	11016
Hydro	6582	6545
Wind	7631	7635
Solar	5810	5810
Geothermal	114	114
Biomass : residues	1007	1011
Biomass : energy crops	9368	9388
Total	**76531**	**76268**

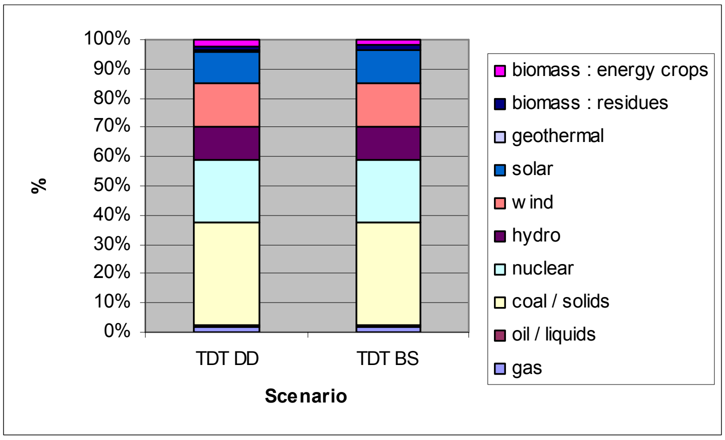


Figure A.1.7 Share of net electricity generation (TDT scenarios, 2050)

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

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

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

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

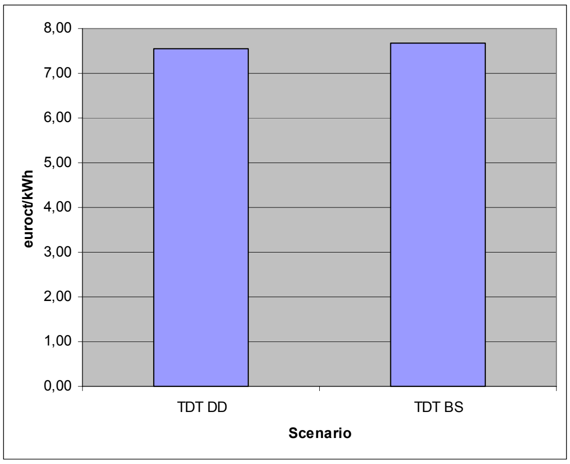


Figure A.1.8 Marginal cost of electricity mix (TDT scenarios, 2050)

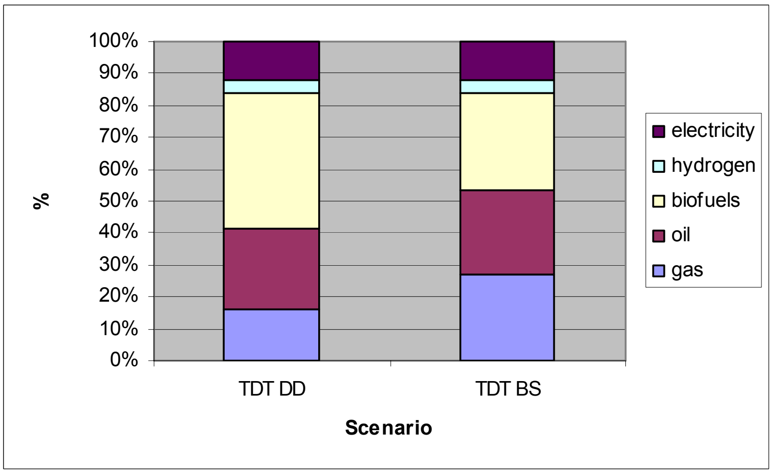


Figure A.1.9 Share of final energy demand in transport sector (TDT scenarios, 2050)

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

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

Appendix 2 Analyses of biomass potentials with IMAGE

A2.1 IMAGE 2 Integrated assessment framework (general description)

IMAGE 2 is an integrated assessment modelling framework describing global environmental change in terms of cause–response chains (Bouwman et al., 2006). The most important subsystems are the "socio-economic system" and the "earth system" (Figure A2.1). In the socio-economic system, detailed descriptions of the energy and food consumption and production are developed using TIMER and agricultural trade and production models. The two main links between the socio-economic system and the earth system are land use and emissions. First, production and demand for food and biofuels lead to a demand for managed land. Second, changes in energy consumption and land-use patterns give rise to emissions that are used in calculations of the biogeochemical circles, including the atmospheric concentration of greenhouse gases and some atmospheric pollutants, such as nitrogen oxides and sulphur oxides. Changes in concentration of greenhouse gases, ozone precursors and species involved in aerosol formation form the basis for calculating climatic change. Next, changes in climate are calculated as global mean changes and downscaled to grid level.

The land-cover sub models in the earth system simulate the change in land use and land cover at 0.5 x 0.5 degrees (driven by demands for food, timber and biofuels, and changes in climate). A crop module based on the FAO agro-ecological zones approach computes the spatially explicit yields of the different crop groups and the grass, and the areas used for their production, as determined by climate and soil quality. Where expansion of agricultural land is required, a rule-based "suitability map" determines the grid cells selected (on the basis of the grid cell's potential crop yield, its proximity to other agricultural areas and to water bodies). The earth system also includes a natural vegetation model to compute changes in vegetation in response to climate change. An important aspect of IMAGE is that it accounts for important feedbacks within the system, such as temperature, precipitation and atmospheric CO_2 feedbacks on the selection of crop types, and the migration of ecosystems. This allows for calculating changes in crop and grass yields and, as a consequence, the location of different types of agriculture, changes in net primary productivity and migration of natural ecosystems.

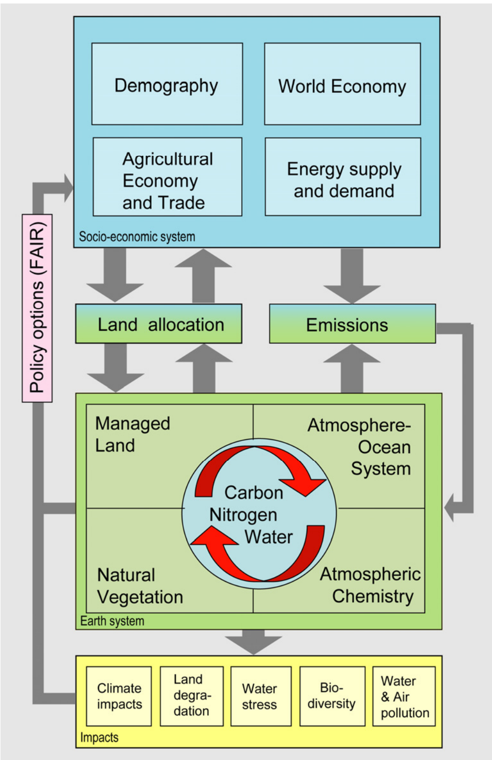


Figure A2.1 IMAGE 2 Integrated Assessment Framework.

A2.2 Bio-energy potential

The potential of renewable bio-energy cas be estimated in IMAGE on the basis of a methodology developed by Hoogwijk (2004) (an generic description is given by De Vries et al. (2007)).

(i) First, the IMAGE model is used to describe land-use in the absence of bio-energy use on the basis of inputs such as 1) food demand and trade, 2) socio-economic and population trends, 3) and greenhouse gas emissions.

(ii) The model assesses which part of the grid cell area can be used for energy production given its physical-geographical (terrain, habitation) and socio-geographical (location, acceptability) characteristics. This leads to an estimate of the geographical potential. Several of these factors are scenario dependent. The geographic potential of biomass production by energy crops is estimated using suitability/availability factors accounting for competing land use options and the harvested rainfed yield of energy crops. An accessibility factor is used for each individual land type that is equal to a value of 0-1. A value of 0 does not allow for any bio-energy production; a value of 1 implies that the grid cell is fully available. By default, bio-energy potential is determined for 1) abandoned agriculture land (accessibility of 0.5-0.75) and 2) natural grass systems (such as savannah, scrubland, tundra and grasslands) (accessibility of 0.25-0.50). Land used for food production, forests, nature reserves and urban areas are excluded from the potential.

(iii) Next, the technical potential accounts for the fact that only part of the energy can be extracted in the form of primary and secondary energy carriers (fuel, electricity), due to limited conversion efficiency. For primary energy, assumptions are made on the 1) yields per hectare for different bio-energy crop types, 2) the conversion into energy. For secondary energy, additional assumptions are made on the efficiency of converting biomass into solid and liquid fuels.

(iv) A final step is to relate this technical potential to the on-site production costs. The information at grid level is finally sorted and presented as supply cost curves to TIMER. Supply cost curves are used dynamically and change over time as result of learning effect. Producing more renewable energy also leads to changes along this curve, and thus to higher costs.

Appendix 3 Biodiversity consequences of bio-energy use

A3.1 Introduction

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

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

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

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

A3.2 Some relevant uncertainties for biodiversity in biofuel assessments

Influence of agriculture productivity, land abandonment and biodiversity recovery

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

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

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

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

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

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

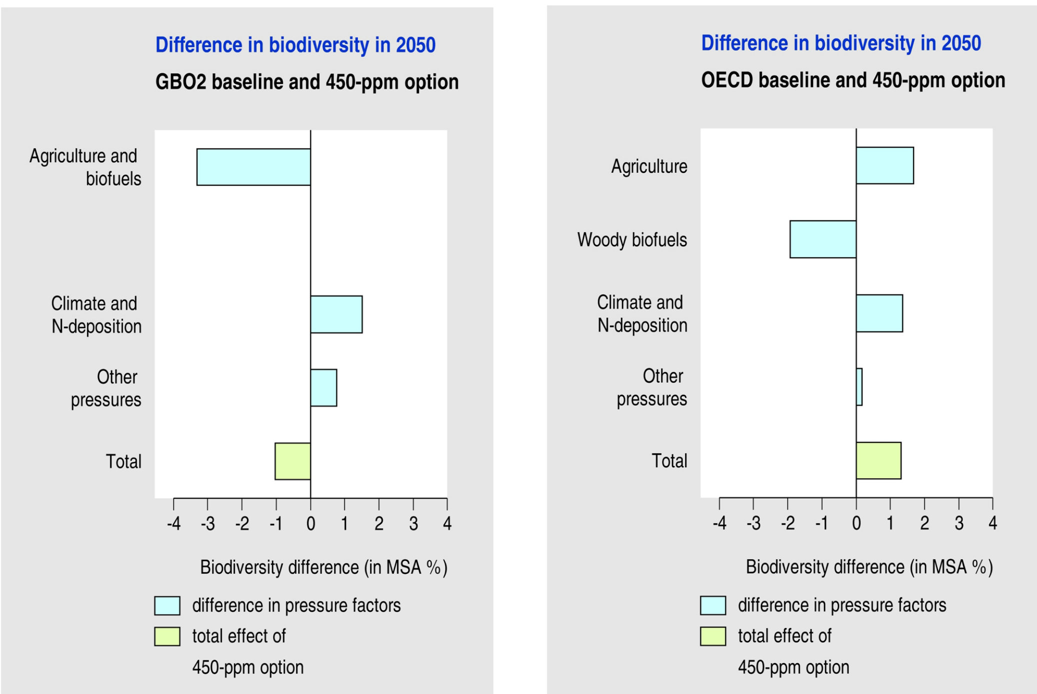


Figure A.3.1 Biodiversity differences for 2 different implementations of a 450-ppm climate change option. Left: GBO2 scenario (CBD and MNP, 2007) and option. Right: OECD scenario and option (OECD, in prep).

A3.3 Influence of Model parameters and characteristics

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

Biodiversity recovery on abandoned lands

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

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

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

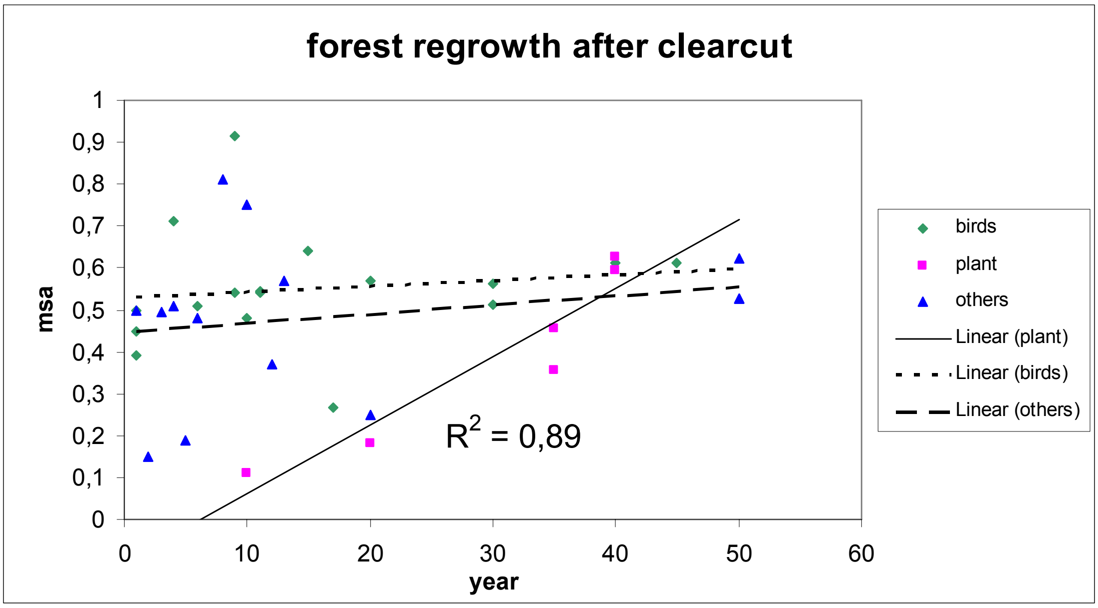


Figure A.3.2 Biodiversity values (as MSA) for different species during recovery after forest clearance. For plants, a significant linear relation was found. Each point presents a different published study, or plot from a sampled sequence (data from GLOBIO literature database).

Taking abandonment and potential recovery into account

In the GBO2 baseline, a total of 4.5 million km^2 of land used for agriculture in 2000 got abandoned and restored to nature by 2050 (mainly grasslands used for grass and fodder in East Asia, Russia, Oceania, the Middle East and Northern Africa). Assuming the slow forest recovery speed for all abandoned areas, the baseline loss should be 1.7% more by 2050[10] (towards 2100, this correction will be smaller as recovery continues). Assuming that all abandoned land is indeed available and used for biofuel production in the 450-ppm option, will turn the negative balance for the option into a net positive effect (+0.7%).

However, abandonment takes place in other regions than most biofuel production (through cost effects). A more detailed analysis of the GBO2 land-use dynamics shows that the abandoned area actually used for biofuel production in the option is about 1.9 million km^2, which presents a correction of +0.7% MSA[11]. The area of biofuels allocated on natural ecosystems (4 million km^2) results in considerable biodiversity loss (through conversion).

[10] Calculation: (4.5 million x 0.5 km^2-MSA) relative to total a terrestrial surface of 132 million km^2.
[11] Calculation: (1.95 million x 0.5 km^2-MSA) relative to total a terrestrial surface of 132 million km^2.

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

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

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

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

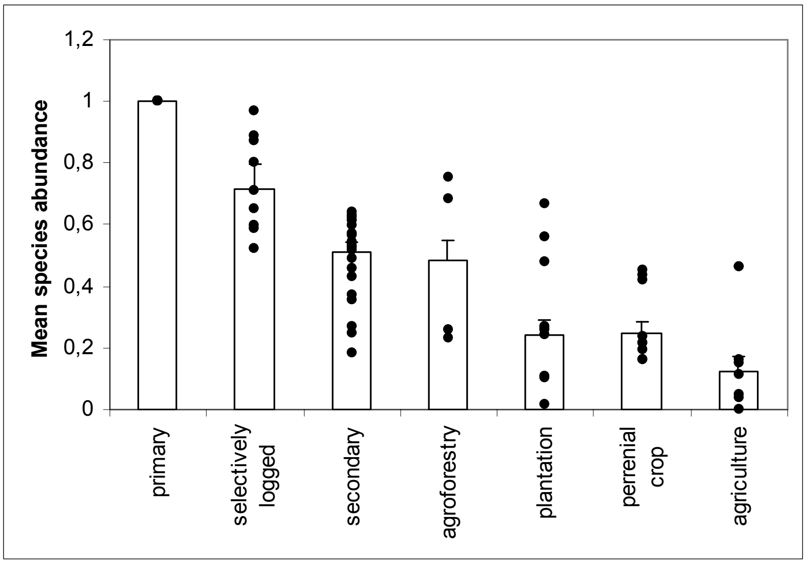


Figure A.3.3 Mean species abundance of original species for different land-use types that form a continuum in land-use intensity(from unimpacted forest to completely converted forest). Data from GLOBIO literature database.

In both 450-options (GBO2 and OECD), mostly 2[nd] generation woody biofuels were grown (selected by TIMER). If these were replaced by 1[st] generation biofuels crops, local biodiversity values would be lower. Taking the same area as for woody biofuel production (about 6 million km^2 in GBO2), a shift to 1[st] generation would mean an additional global biodiversity loss of 0,9% (MSA) in the 450-options[12]. The MSA values for agro-forestry systems are higher than those for

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

plantations and perennial crops, but the potential for biofuel production in these systems will probably not be high. Most of them are in use for valuable cash crops such as coffee and cocoa, but may be a source of local wood fuel supply.

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

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

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

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

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

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

The GLOBIO modelling concept is based on the homogenization process that leads to changes in local abundance of species (= number of individuals per species) and ultimately local disappearance of species, due to an array of pressure factors. In the GBO2 scenario study, the predicted biodiversity decline between 2000 and 2050 due to climate change was about 3% of the total decline of 7,5%. This is an indication of local change in species abundance, due to changing environmental conditions (temperature, rainfall and others). The 3% MSA loss through climate change can be visualized as the complete loss of all natural elements in an area the size of about 4 million km^2 (= 100 times the size of the Netherlands). It does not express the total, worldwide extinction of species. The climate change response is (surprisingly) close to the

MA example. Both approaches look at low spatial levels, using land-use dynamics from the IMAGE model.

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

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

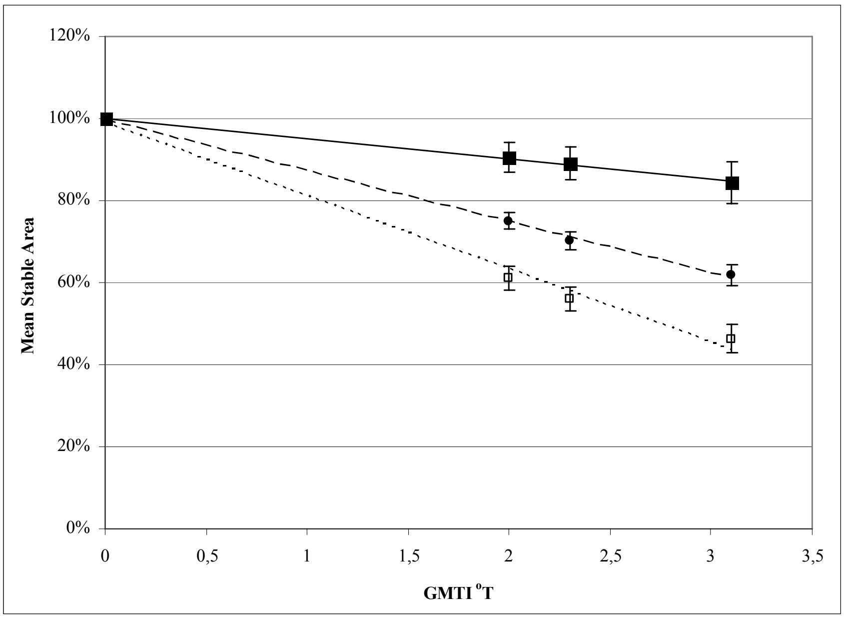


Figure A.3.4 Dose response relationships used for GLOBIO, describing the relation between global temperature change and the mean stable area of species in a specific biome. From top to bottom: tundra, temperate forest, grassland and steppe.

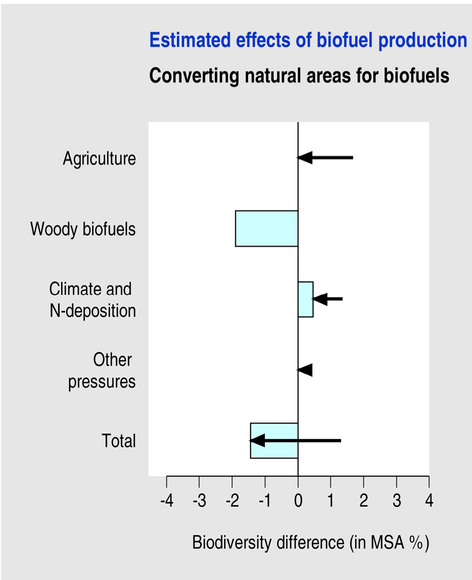
Combining different climatic models on temperature sensitivity, in combination with IMAGE and GLOBIO calculations could give further information on the sensitivity of the biodiversity response. Systematically covering all issues is an elaborate subject for further analysis. As a first estimate, the mentioned temperature range (1.5 to 4.5 K) can be taken as extreme values, and can be related to the calculated global 3% MSA response in the GBO2 baseline (at a baseline projection for ΔT of 1.85K by 2050). Assuming complete linearity and no further changes in natural areas will then lead to a range of temperature responses from 1.8% to 5.4% MSA[13].

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

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

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

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



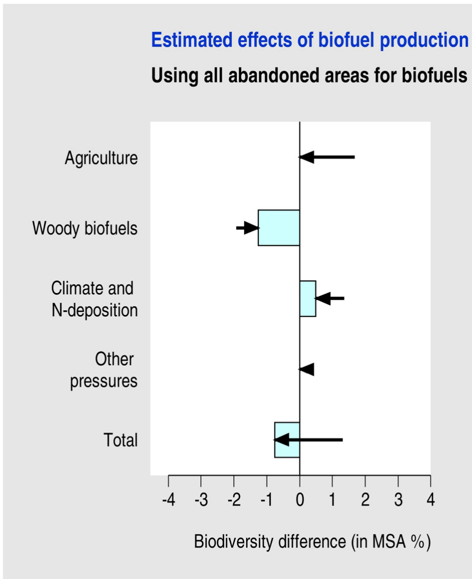


Fig A.3.5 Estimated effects of hypothetical biofuel scenarios. Left: effects of converting natural areas for biofue. Right: using all abandoned areas for biofuel production. Black arrows indicate corrections on the OECD 450-ppm option.

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

For instance, with the OECD 450-option as starting point, we can assume:
- the same amount of woody biofuels is produced
- agricultural land-use does not change (no additional abandonment or compact agriculture)
- about a third of the greenhouse gas emission reduction is brought about by biofuel production (net effect of woody biofuels), and will results in a third of the climate change response (assuming linear effects)

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

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

A3.4 Integration of results

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

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

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

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

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

Appendix 4 Use of degraded lands for biomass production

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

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

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

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

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

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