CLIMATE CHANGE

Scientific Assessment and Policy Analysis

WAB 500102 024

Can biofuels be sustainable by 2020?

An assessment for an obligatory blending target of 10% in the Netherlands

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Can biofuels be sustainable by 2020? An assessment for an obligatory blending target of 10% in the Netherlands

Report
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January 2009

This study has been performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB), project “Feasible, affordable and socially acceptable biofuels production levels for 2020”.

Wetenschappelijke Assessment en Beleidsanalyse (WAB) Klimaatverandering

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.

De analyses en assessments beogen een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. De activiteiten hebben een looptijd van enkele maanden tot maximaal 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 en zonodig buitenlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van de deelnemers van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Doelgroepen zijn 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 PBL, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het PBL is hoofdaannemer en fungeert als voorzitter van de Stuurgroep.

Scientific Assessment and Policy Analysis (WAB) Climate Change

The Netherlands Programme on Scientific Assessment and Policy Analysis Climate Change (WAB) 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.

WAB conducts 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 a maximum of one 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 (PBL), the Royal Dutch Meteorological Institute, the Climate Change and Biosphere Research Centre (CCB) of Wageningen University and Research Centre (WUR), the Energy research Centre of the Netherlands (ECN), the Netherlands Research Programme on Climate Change Centre at the VU University of Amsterdam (CCVUA), the International Centre for Integrative Studies of the University of Maastricht (UM/ICIS) and the Copernicus Institute at Utrecht University (UU) is responsible for the implementation. The Netherlands Environmental Assessment Agency (PBL), as the main contracting body, is chairing the Steering Committee.

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Preface

The Netherlands government has proposed to install targets for obligatory blending of transport fuels with biofuels to increase energy security of the Netherlands and to reduce greenhouse gas (GHG) emissions. Netherlands biofuels should thereby comply with sustainability criteria as has been set out in the so called Cramer criteria. In this respect we have been asked by the Netherlands' Ministry of Housing, Spatial Planning and the Environment to make an assessment of the realistic availability of sustainable biofuels by 2020 for the Netherlands.

We have decided to assess the likelihood for certain processes to occur in implementing the new biofuels sector up to 2020, based on existing knowledge and information, literature review of most relevant documents and own expert judgment. The study also aims to create some clarity in the debates about biofuels by reflecting on the assumptions underlying the outcomes of some influential documents. We have refrained from formulated policy recommendations as to how to govern desired developments, as these could be considered in subsequent studies.

We would like to thank the international reviewers from the International Food Policy Research Institute (IFPRI) and the International Water Management Institute (IWMI) for their critical comments to warrant the scientific quality of the report. The feedback and constructive suggestions by policy makers from various ministries have served to maintain the focus on the research objectives. The organisational support by Irene Gosselink and the editing effort of Foluke Quist have helped in making this report readable. The study has been performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB).

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Introduction

Biofuels are being proposed by the European Commission and the Netherlands as part of an integral approach to reduce GHG emissions and increase security of energy supply, while supporting rural development. To prevent unsustainable developments, the political discussion on biofuels has been accompanied by sustainability criteria. Recent world food problems and scientific analyses questioning the effectiveness of biofuels as a means to reduce GHG emissions have strengthened this focus on sustainability criteria for biofuels.

This study looks into the expected near future developments in the production of biofuels to assess the availability of sustainable biofuels for the Netherlands in 2020 and the implications for sustainability components as outlined and accepted by society at large, including the Netherlands government, in the Cramer criteria.

Rather than exploring production potentials, this study has assessed the likelihood for certain processes to occur in implementing the new biofuels sector up to 2020, based on existing knowledge and information, review of most relevant documents and own expert judgment. The focus of this study is on agricultural development, conversion technologies, investments and socio-economic consequences. Due to remaining uncertainties surrounding future developments in biofuels, two perspectives have been presented on the perceived impacts of Dutch policies for obligatory blending targets for the transport sector by 2020 on various sustainability criteria. The perspectives are intended to explore the width of the range of possible outcomes, and to reflect diverging opinions on the net impacts of large-scale expansion of biofuels usage up to 2020. Sustainability is reflected upon against the background of some international conventions regarding climate change, biodiversity and, hunger and poverty.

Agricultural development

A critical variable in future outcomes of analyses on production potentials and availability of feedstock for biofuels is the expected increase in agricultural productivity. Most studies estimate future yield levels through extrapolation of past trends, in some cases corrected for economic investment levels related to food prices, or constrained by yield plateaus. More realistic estimates should however be explicitly based on production ecological principles. Moreover, recent development in underlying drivers for agricultural productivity should be accounted for in short-term projections. The decreasing availability of water, fertile land and other natural resources, decreasing increase in crop production potential, decreasing investments in agricultural infrastructure such as irrigation facilities, and the decrease in the overall investments in agricultural research and development over the past decade or two are likely to put limitations to yield increases in the coming decade or more. Agricultural development is a long term process because of large time lags. Reviving the speed of agro-technical innovations, such as breeding a new variety, installing a dam, designing modified agronomic practices, may take a decade or more. This is also true for their implementation because these require socio-economic and institutional changes including a change in behaviour of farmers and other actors in and outside the sector.

As a consequence, the group states, in line with various other studies, that globally more rather than less land will be needed for agriculture for food and feed during the coming decade or more. The rate of productivity increase is not likely to keep up with the strongly increasing demand for food and feed. Moreover, in addition to the demand for food as projected by economic models, higher supply rates are needed to adequately feed food insecure people.

Based on our expert judgement we find it unlikely that much feedstock will be produced on marginal lands by 2020, as exploitation requires large amounts of external inputs including water and nutrients and because institutional and infrastructural conditions have to be put in place as well. Improving the ecological conditions of marginal lands takes decades, while yield performance will be low and highly variable. These conditions do not favour a rapid exploitation of these regions. As a consequence, feedstock production for biofuels will have to take place on fertile lands with sufficient availability of water. Since and because a large part of the feedstock will be food-based, this implies increased competition for natural resources with food production, apart from direct competition for food.

GHG emissions and biodiversity

Biofuels originating from oil, sugar or starch crops are defined here as first generation biofuels, and from lignocellulosic crops or residues as second generation biofuels. Literature review shows that the direct GHG savings of first generation biofuels are generally positive within the production chain, provided good agronomic management. Their GHG performance depends on how by-products of biofuels production are accounted for, such as press cake from oilseeds and DDGS from cereals (Distiller's Dried Grain & Solubles). Savings can be offset however under poor management, for instance due to the loss of soil organic matter, or high emissions of N_2O if too much nitrogen fertilizers are used. Second generation biofuels tend to show more favourable percentages of GHG emission reductions, modestly varying between different conversion technologies.

As the agricultural acreage for food production will increase in the coming decade, production of food and non-food based feedstock for biofuels will put a direct or indirect claim on natural lands. The land clearing for the production of biofuels will cause land use changes, anywhere in the world, that can lead to substantial GHG emissions, depending on the carbon stocks of the land taken into production. Studies have shown that conversion of carbon-rich lands results in CO_2 emissions that offset the direct GHG emissions reductions and lead to a worsening rather than a mitigation of GHG emissions and climate change.

Clearing of land inherits overall loss of biodiversity. Also, intensification and large scale production systems lead to a decrease in biodiversity at the field and regional scale. Biofuels will add to these losses.

Conversion technology and production costs

Investments costs have been estimated in other studies to comprise a minor part of production costs for first generation biofuels, while feedstock costs usually cover 80 to 90% of them. However, investment costs are substantially higher for second generation biofuels. Consequently, first generation plants can adjust their production volume to the margin between biofuels prices and cost levels of feedstock, with a dampening effect on feedstock prices when they would rise. On the other hand second generation plants will need to pursue their operations even in poor biofuel market conditions to recover their investments. However, as these biofuel routes compete less strongly with food production, this is likely to have only a limited effect on food prices.

Second generation plants currently under development are ethanol plants from lignocellulosic feedstock (mainly in the USA) and FischerTropsch-diesel (FT) initiatives (mainly in Europe). Lignocellulosic ethanol initiatives have the relative advantage that the cellulose hydrolysis step can be installed upfront in ethanol plants, allowing for a gradual shift in feedstock as the cellulose processing technology grows mature. FT-diesel plants do not have this advantage; they require relatively substantial initial investments. Upscaling of second generation plants depends heavily on the yet-to-be proven commercial viability of the technology, and availability of funding for research, development and demonstration. The proportion of second generation biofuels by 2020 therefore depends on a large number of developments and has been guestimated by the research group to range from 0% to maximally 40%.

Direct costs of biofuels should be evaluated for the entire production chain and depend on feedstock, assumptions on value of by-products and conversion efficiency. Precise estimates cannot be provided but indicative values have been derived by the authors of this study to create a sense for this issue. Production costs are estimated to range from 15 to 25 €/GJ. When translating this to additional fuel costs at the pump, future oil prices are an additional factor causing uncertainty. The most conservative assumptions (high biofuel production costs and low oil prices) lead to additional costs of 6 €ct per litre for meeting the 10% biofuels target; most optimistic assumptions (low biofuel production costs and high oil prices) lead to negligible costs or even a small benefit.

Economic considerations

Most studies surveyed estimate that blending obligations of biofuels will increase food prices on average by 10 to 30% under equilibrium conditions. Furthermore, food prices will be more strongly linked to energy prices, thereby setting a floor and ceiling to prices, that could serve as a new way of price intervention and stabilize prices. However, any volatility in energy prices may also be transferred to food markets. Moreover, mandatory blending targets will further add to the instability because it implies extra demand even during price hikes.

Biofuels are one of the determinants of the recent price hikes in food, with estimated contributions in literature ranging from 30 to 80%, and as such has contributed to the recently increased problems of food insecurity, though it is not expected to be a dominant factor in the long term. While both opportunities and threats may arise from the expected price effects on food, the group finds that development opportunities for small farmers remain unclear as economies of scale in production and processing are important conditions for the biofuels market. Large scale development of biofuels can create opportunities for development, but may also crowd out other activities, resulting in displacement effects and ultimately leading to an imbalance in wealth. Current ongoing projects show that small scale initiatives for local use of small amounts of biofuels may catalyze rural development such as to facilitate transport or operation of small equipment like irrigation pumps and pressing, but are not likely to contribute to any significant degree to the international trade.

Reviews learn that production costs for biofuels as a means to reduce GHG emissions are overly expensive compared to alternatives. Without policy support, the biofuels market would make a contribution to the transport sector of 2-3% by 2020, which makes policy interventions, including obligations and/or subsidies, essential if a target of 10% is to be attained. The group feels that increasing energy security and the development of a new economic sector ought to be considered also in judging these costs. The biofuels target will increase transport fuel prices and add costs to society.

Uncertainties and perspectives

Uncertainties as identified in this study have been translated by the research team into plausible ranges for calculating requirements for land, reductions in GHG emissions and replacement of food production. Imposing a worldwide 10% obligatory blending targets for biofuels, has been calculated by us to put a claim on 85-176 million hectares of fertile land, depending on the fraction first or second generation biofuels, the fraction of residues in the second generation feedstock, the composition of crops in the feedstock and the crop yield levels assumed. For the Netherlands, we calculated that an acreage of 612 to 810 thousand hectares would be required; an amount nearing the current arable area in the Netherlands of some 900 thousand hectares. This implies that the Netherlands will be almost fully dependent on import of feedstock or biofuel. On these lands tied up for biofuel production for the Netherlands, enough food could be grown to feed 2.7 to 3.6 million people with a diet currently consumed in the EU. The 10% obligatory blending target leads to a direct reduction of 1.3-1.8% from the total Netherlands GHG emissions, obtained in the production chain. This reduction will however be reduced to zero by indirect emissions when only a quarter to a third of the required land would originate from natural lands.

The conclusions from this study show that not all the sustainability criteria as set by Cramer for biofuels will be met if the Netherlands aims at a 10% blending by 2020. One perspective assumes that even significant changes within the coming decade will not be able to reduce the expected negative implications of biofuels. The other perspective assumes that major efforts could be taken to reduce negative effects, though calls for careful interpretation. With that, biofuels are not likely to contribute to objectives as related to the Convention on Biological Diversity, the UN Framework Convention on Climate Change (UNFCCC) and some of the MDGs.

Samenvatting

Introductie

Biobrandstoffen worden door de Europese Commissie en de Nederlandse overheid voorgesteld als onderdeel van een integrale benadering om de emissie van broeikasgassen te reduceren en om de energiezekerheid te vergroten, waarbij tevens rurale ontwikkeling gestimuleerd wordt. Om onduurzame ontwikkelingen te voorkomen wordt een politieke discussie gevoerd ten aanzien van duurzaamheidscriteria. Recente problemen met voedselzekerheid in de wereld en wetenschappelijke inzichten die de effectiviteit van biobrandstoffen in twijfel trekken als middel om broeikasgasemissies te reduceren, hebben de aandacht voor duurzaamheidscriteria versterkt.

Om de beschikbaarheid van duurzame biobrandstoffen voor Nederland in 2020 te schatten, is er in deze studie gekeken naar de mogelijke ontwikkelingen die te verwachten zijn op het gebied van de productie van biobrandstoffen in de nabije toekomst. Daarbij zijn eveneens de gevolgen bestudeerd voor verschillende componenten van duurzaamheid die uiteengezet en geaccepteerd zijn door de samenleving, inclusief de Nederlandse overheid, in de zogenaamde Cramer criteria.

We hebben ons niet gericht op het bestuderen van de vele analyses van productie potenties, maar een inschatting gemaakt van de meest waarschijnlijke ontwikkelingen van processen die zich zullen voltrekken bij de implementatie van de nieuwe biobrandstoffensector tot 2020. Dit is gebaseerd op bestaande kennis en informatie, bestudering van relevante documenten en onze eigen deskundigheid. Daarbij hebben we ons gericht op de landbouwkundige ontwikkelingen, conversietechnologieën, investeringsbehoeften en sociaaleconomische consequenties. Vanwege een aantal onzekerheden ten aanzien van toekomstige ontwikkelingen, zijn er twee perspectieven geschetst over de mogelijke gevolgen voorde duurzaamheid van het Nederlandse beleid van verplichte bijmenging van biobrandstoffen voor de transportsector in 2020. De perspectieven zijn bedoeld om het bereik aan mogelijke uitkomsten te schetsen en om te reflecteren op de divergerende opinies over de invloed van grootschalige expansie van biobrandstoffengebruik tot 2020. Er is op duurzaamheid gereflecteerd tegen de achtergrond van een aantal internationale conventies zoals klimaatverandering, biodiversiteit en, honger en armoede.

Landbouwkundige ontwikkeling

Een cruciale variabele in analyses van productie potenties en beschikbaarheid van biomassa voor biobrandstoffen in de toekomst is de verwachte toename van landbouwproductiviteit. De meeste studies schatten die toename in door extrapolatie van trends uit het verleden, in sommige gevallen aangepast voor economische investeringsniveaus gerelateerd aan voedselprijzen, of gelimiteerd door maximale opbrengstniveaus. Realistische inschattingen zouden echter ecologische productieprincipes als uitgangspunt moeten hanteren. Verder moeten onderliggende productiefactoren die de landbouwproductiviteit bepalen expliciet moeten worden meegenomen, zeker in korte termijn analyses. De afnemende beschikbaarheid aan zoet water, vruchtbare gronden en andere natuurlijke hulpbronnen, afnemende toename van het productiepotentieel van gewassen, afnemende investeringen in landbouwkundige infrastructuur, zoals irrigatie faciliteiten, en de algehele afnemende investeringen in landbouwkundige onderzoek en ontwikkeling over de afgelopen twee decennia zullen allen de verhoging van gewasopbrengsten beperken gedurende het komende decennium en daarna. Landbouwontwikkeling is een lange termijn proces vanwege langdurige processen. Het revitaliseren van landbouwkundige innovaties zoals de veredeling van gewassen, het bouwen van een dam, en het ontwerpen van nieuwe agronomische praktijken kunnen 10 jaar of langer duren. Dit geldt ook voor de implementatie van technische innovaties omdat het sociaaleconomische en institutionele veranderingen vereist inclusief een verandering in gedrag van boeren en andere actoren binnen en buiten de sector.

Gebaseerd op deze feiten wordt door de onderzoeksgroep, in overeenstemming met verschillende andere studies, geconcludeerd dat meer, in plaats van minder landbouwgrond nodig zal zijn voor de productie van voedsel gedurende de komende decennium of zelfs langer. De snelheid waarmee de productiviteit ofwel de gewasopbrengsten in de landbouw kunnen worden vergroot zal niet gelijk op kunnen gaan met de sterk stijgende vraag naar voedsel. Bovendien geldt dat bovenop de koopkrachtige vraag naar voedsel zoals geprojecteerd in economische analyses, een nog grotere productietoename nodig zal zijn om voedselonzekere mensen van een adequate hoeveelheid voeding te voorzien.

Gebaseerd op onze expertise vinden we het onwaarschijnlijk dat er veel biomassa geproduceerd zal worden in marginale gebieden in 2020, omdat de benutting van deze gebieden grote hoeveelheden aan externe inputs vergt zoals water en nutriënten en omdat instituties en infrastructuur nog moeten worden aangelegd. Het verbeteren van de ecologische productiecapaciteit van marginale gronden duurt vele decennia zelfs met een hoog niveau van inputs, terwijl opbrengsten laag en zeer variabel zullen zijn. Deze condities bevorderen geen snelle benutting van marginale gebieden. Het gevolg is dat de productie van biomassa op vruchtbare gronden zal plaatsvinden waar voldoende water beschikbaar is. Omdat een groot deel van de biomassa voor biobrandstoffen uit voedsel zal bestaan, heeft dit tot gevolg dat de concurrentie met voedselproductie om natuurlijke hulpbronnen zal toenemen, naast de directe concurrentie om voedsel.

Emissie van broeikasgassen en biodiversiteit

Biobrandstoffen gemaakt van olie-, suiker- en zetmeelgewassen zijn hier gedefinieerd als eerste generatie en van lignocellulose gewassen of residuen als tweede generatie biobrandstoffen. Literatuuranalyse geeft aan dat de directe reducties in emissie van broeikasgassen over het algemeen positief zijn binnen de productieketen, mits de gewassen op een goede agronomische manier zijn geteeld. De emissiereductie wordt bepaald door de manier waarop bijproducten die vrijkomen bij de productie van biobrandstoffen worden meegewogen, zoals het persmeel van oliegewassen en het digestaat van granen (DDGS). Deze besparingen kunnen echter teniet gedaan worden door slechte agronomische praktijken die bijvoorbeeld leiden tot verlies van bodem organische stof of door een hoge emissie van N_2O bij te hoge toediening van stikstofkunstmest. Tweede generatie biobrandstoffen geven iets betere percentages reductie in emissie van broeikasgassen waarbij weinig variatie optreedt tussen verschillende conversie technieken.

Aangezien het landbouwkundige areaal voor voedselproductie zal toenemen gedurende de komende decennia, zal de productie van energiegewassen (voedsel en niet-voedsel) voor biobrandstoffen een directe en indirecte claim leggen op natuurlijke gebieden. De ontginning van natuurlijke gebieden leidt tot landgebruiksveranderingen, waar ook ter wereld, en dit resulteert op zijn beurt in substantiële emissies van broeikasgassen, afhankelijk van de opgeslagen hoeveelheden koolstof in de vegetatie en de bodem. Verschillende studies hebben aangetoond dat de broeikasgasemissies bij ontginning van koolstofrijke gebieden de reductie in de keten van biobrandstoffen ruimschoots overtreffen en daarmee leiden tot een vergroting van het klimaatprobleem in plaats van een verkleining.

Het ontginnen van natuurlijke gronden gaat gepaard met verlies van biodiversiteit. Ook zal intensivering en schaalvergroting voor de nodige productieverhoging leiden tot verlies van biodiversiteit op veld en regionaal niveau. Biobrandstoffen zullen aan deze verliezen bijdragen.

Conversietechnologie en productiekosten

Uit andere studies blijkt dat investeringskosten slechts een klein deel uitmaken van de productiekosten van eerste generatie biobrandstoffen, terwijl de kosten van biomassa wel 80 tot 90% kunnen bedragen. Investeringen in tweede generatie biobrandstoftechnologie zijn daarentegen substantieel hoger. Dit houdt in dat eerste generatie fabrieken hun productievolume kunnen aanpassen aan winstmarges tussen de prijs van biobrandstoffen en het kostenniveau van de biomassa waardoor dit een drukkend effect heeft op de stijging van voedselprijzen. Tweede generatie fabrieken zullen hun productie echter in stand moeten houden onder ongunstige marktomstandigheden omdat ze hun investeringskosten moeten terugverdienen. Aan de andere kant zullen deze biomassastromen minder sterk concurreren met voedsel en daarmee slechts een klein effect hebben op de prijzen van voedsel.

Tweede generatie fabrieken die momenteel worden gebouwd zijn bedoeld voor de productie van ethanol uit lignocellulose (met name in de VS) en synthetische diesel met behulp van de Fischer-Tropsch technologie (met name in Europa). Het voordeel van de verwerking van lignocellulose is dat het als een voorproces kan worden geïntegreerd in eerste generatie ethanolfabrieken waardoor een geleidelijke overgang van eerste naar tweede generatie mogelijk wordt bij een zich ontwikkelende markt. FT diesel heeft dit voordeel niet. De fabrieken voor dit proces vereisen substantiële initiële investeringen. De opschaling van tweede generatie fabrieken is erg afhankelijk van technologieën waarvan nog bewezen moet worden dat ze economisch competitief kunnen zijn, en van de beschikbaarheid van fondsen voor onderzoek, ontwikkeling en demonstratie. Het aandeel tweede generatie biobrandstoffen zal dan ook van een groot aantal ontwikkelingen afhankelijk zijn en is door de onderzoeksgroep geschat op 0% tot een maximum van 40% in 2020.

Directe kosten van biobrandstoffen moeten worden geëvalueerd voor de gehele productieketen en hangen af van de gebruikte biomassa, aannames ten aanzien van de waarde van de bijproducten en conversie efficiëntie. Exacte berekeningen kunnen niet worden gemaakt, maar ramingen door de auteurs van deze studie geven indicaties om een gevoel voor de orde van grootte te krijgen. Productiekosten worden geschat op 15 tot 25 €/GJ. Bij het omzetten naar prijzen aan de pomp vormen toekomstige olieprijzen een additionele bron van onzekerheid. De meest conservatieve aanname (hoge productiekosten van biobrandstoffen en lage olieprijzen) leidt tot additionele kosten van 6 €cnt per liter bij een doelstelling van 10% en de meest optimistische aanname (lage productiekosten voor biobrandstoffen en hoge olieprijzen) leidt tot een verwaarloosbare verhoging of zelfs tot een kleine verlaging.

Economische overwegingen

De meeste studies die zijn bestudeerd geven aan dat een verplichte bijmengdoelstelling van biobrandstoffen zal leiden tot een verhoging van de evenwichtsprijzen van voedsel van gemiddeld 10-30%. Voedselprijzen zullen sterker gekoppeld zijn aan energieprijzen, die daardoor een bodem- en plafondprijs vastleggen en dienst kunnen doen als mechanisme voor prijsinterventies en stabilisering van voedselprijzen. Echter, de fluctuaties in energieprijzen zullen worden overgeheveld naar de voedselmarkt. Voorts zal een verplichtende bijmengdoelstelling leiden tot verdere instabiliteit van de voedselprijzen omdat de vraag naar biomassa blijft bestaan, ook in geval van hoge grondstofprijzen.

Biobrandstoffen zijn een van de veroorzakers van de recente stijgingen van voedselprijzen, waarbij de geschatte bijdrage in de literatuur varieert van 30 tot 80%, en hebben als zodanig bijgedragen aan de recente voedselproblemen in de wereld. Het wordt niet verwacht dat ze een dominante factor in de toekomst zullen zijn. Hogere prijzen voor voedsel kunnen kansen bieden en ook bedreigingen vormen, maar de onderzoeksgroep vindt dat de kansen voor kleine boeren onzeker blijven omdat economische schaalvoordelen in de productie en verwerking van biobrandstoffen belangrijke voorwaarden zijn voor een levensvatbare marktpositie. Grootschalige productie van biobrandstoffen kan mogelijkheden voor algehele ontwikkeling bieden, maar kan ook andere activiteiten verdringen en daarmee leiden tot een onevenwichtige verdeling van welvaart. Lopende projecten lijken uit te wijzen dat kleinschalige initiatieven voor lokaal gebruik van kleine hoeveelheden biobrandstoffen als een katalysator kunnen dienen voor rurale ontwikkeling zoals voor het verbeteren van transport of het aandrijven van pompen voor bijvoorbeeld irrigeren of persen. Het is echter onwaarschijnlijk dat deze ontwikkelingen ook maar enige relevante bijdrage zullen leveren aan de internationale productie en handel van biobrandstoffen.

Literatuur wijst uit dat productiekosten van biobrandstoffen als middel om emissies van broeikasgassen te reduceren excessief hoog zijn vergeleken met alternatieven. Zonder beleidsondersteuning zou het aandeel biobrandstoffen in de transportenergiemarkt in 2020 gelijk zijn aan 2-3%, waardoor beleidinterventies, inclusief verplichtingen en/of subsidies essentieel zijn om het doel van 10% te halen. De groep vindt dat het ontwikkelen van een nieuwe energiesector eveneens moet worden meegewogen in de beoordeling van deze kosten. De bijmengverplichting zal de kosten van transportbrandstoffen verhogen en leiden tot additionele kosten voor de samenleving.

Onzekerheden en perspectieven

De aangegeven onzekerheden in deze studie zijn door de onderzoekers vertaald naar aannemelijke marges om het beslag op land, de reductie van broeikasgasemissies en de verdringing van voedselproductie uit te kunnen rekenen. Zo is door ons uitgerekend dat het opleggen van een wereldwijde 10% doelstelling voor biobrandstoffen beslag zal leggen op 85-176 miljoen hectare vruchtbare grond. Dit beslag is afhankelijk van de fractie eerste of tweede generatie biobrandstoffen, de fractie residuen in de tweede generatie biomassa, de samenstelling van de gewassen die worden gebruikt en de aangenomen opbrengstniveaus van die gewassen. Voor Nederland hebben we uitgerekend dat 612-810 duizend hectare nodig is wat vrijwel overeenkomt met het volledige akkerbouwareaal van Nederland van ongeveer 900 duizend hectare. Dit betekent dat Nederland vrijwel volledig afhankelijk zal zijn van import van biomassa voor biobrandstoffen. Op het areaal voor de productie van deze biomassa kan een hoeveelheid voedsel worden geproduceerd waarmee 2.7 tot 3.6 miljoen mensen kunnen worden gevoed met een Europees dieet. Een verplichtende doelstelling van 10% biobrandstoffen geeft een reductie in emissie van broeikasgassen van 1.3-1.8% van de totale uitstoot door Nederland alleen bezien vanuit de productieketen. Echter, deze verminderde uitstoot zal totaal teniet worden gedaan indien slechts een kwart tot een derde van het areaal zou bestaan nieuw ontgonnen gebieden.

Deze studie concludeert dat bij een 10% bijmengdoelstelling door Nederland in 2020 niet aan alle duurzaamheidscriteria kan worden voldaan zoals vastgesteld door de commissie Cramer voor biobrandstoffen. Eén perspectief geeft aan dat zelfs significante veranderingen binnen het komende decennium de negatieve effecten van biobrandstoffen niet zal kunnen verminderen. Een ander perspectief veronderstelt dat omvangrijke inspanningen moeten worden gedaan om die negatieve effecten te reduceren, waarbij wel wordt opgeroepen tot voorzichtige interpretatie ervan. Hiermee is het onwaarschijnlijk dat biobrandstoffen positief zullen bijdragen aan doelstellingen zoals geformuleerd in de Conventie over biodiversiteit, de VN conventie over klimaatverandering en een aantal Millennium doelstellingen.

1 Introduction

Currently there is much debate about the sustainability of biofuels. The Netherlands government has proposed to install targets for obligatory blending of transport fuels with biofuels to increase energy security of the Netherlands and to reduce GHG emissions. For 2020 it intends to impose a target of 10%, following the objectives in the draft EU Renewable Energy directive, and is considering to raise its own targets to 20%, under the pre-condition that biofuels are sustainable. To this aim it has set out sustainability criteria, named after our current Minister of Environment the Cramer criteria, of which most components are further discussed within the framework of sustainability criteria under construction by the European Commission.

We have been asked by the Netherlands' Ministry of Housing, Spatial Planning and the Environment to make an assessment of the realistic availability of sustainable biofuels by 2020 for the Netherlands. The assessment had to be done in the broader European and global context of demand for biofuels, indicating associated costs and price for the Netherlands, the amount of GHG reduction that could be obtained and the consequences for displacement in terms of land, water, biodiversity and food production. Hence, the sustainability is reflected upon against the background of some international conventions, including on climate change, biodiversity and, hunger and poverty.

Many current policy documents to the Ministry have emphasized long term production potentials of biofuels e.g. by 2050 and beyond. The generated information is likely to be incongruent with information needed for the identification of policy measures to implement short term targets for 2020. We have therefore reviewed the likelihood for certain processes to occur in implementing the new biofuels sector up to 2020, based on existing knowledge and information, literature review of relevant documents and own expert judgment. The study has a descriptive nature of these likely developments and presents a synthesis of possible consequences, but has explicitly not formulated policy recommendations as to how to govern desired developments. These could be considered in subsequent studies.

The reasons for the introduction of biofuels by policy in different parts of the world, primarily OECD countries, and the subsequent debate about the need to install sustainability criteria that have to be complied with in the production chain of biofuels have been elaborated in chapter 1. Integrated are scientific and public debates and methodological difference between studies that explain differences in outcomes, for instance with regard to agronomic or economic availability of biofuels.

The development in agricultural productivity is a key driver in the entire debate about the availability of land and other natural resources for biofuels in relation to the increasing demand for food and feed. These developments have been assessed in chapter 2 following production ecological principles to reflect on existing studies about productivity increase and developments in the recent past that have served as a basis to assess likely development in the near future.

Important to the debates is the likelihood of the development of technologies (chapter 3) and the required investments in processing facilities (chapter 4). This is certainly true for the production of second generation biofuels, as these are presumed to have less adverse socio-economic and environmental impacts as first generation biofuels. Though it is not easy to estimate production costs, some values have still be derived to give a sense of “ballpark” magnitudes.

Socio-economic implications along with costs and benefits to society following intended biofuels policies have been elaborated in chapter 5. More specifically, implications for costs for GHG emission reductions, implications for food prices, price hikes and hunger, and development opportunities have been assessed.

An overall synthesizes sketching the uncertainties in the development processes and identifying robust conclusions with regard to the sustainability of biofuels have been presented in chapter 6. The uncertainties have been translated into plausible ranges for calculating requirements for land, reductions in GHG emissions and replacement of food production. Also, two possible perspectives about the impacts of Dutch obligatory blending targets for 2020 on various sustainability criteria have been presented, to explore the width of the range of likely outcomes, and to reflect diverging opinions on the net impacts of large-scale expansion of biofuels production.

2 Bioenergy and biofuels – general introduction

2.1 The case for bioenergy and biofuels

On 23 January 2008, the European Commission released its climate and energy policy package, including European targets for greenhouse gas reductions and shares of renewables for all EU Member States in 2020 (EC, 2008). This package contains proposals for Directives following initiatives by the European leaders in March 2007. At that time, the European Council agreed to put forward an ambitious climate and energy policy package, including targets for greenhouse gas emission reduction, energy savings and share of renewables in the total energy consumption (EU, 2007). The broader intention of the 'Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources' is to set a binding target to increase the level of renewable energy in the EU energy mix to 20% by 2020.

However, climate change is not the only reason to stimulate renewables in the EU. As the European Commission states: 'the European Union's increasing dependence on energy imports threatens its security of supply and implies higher prices. Therefore, boosting investment in energy efficiency, renewable energy and new technologies has wide-reaching benefits and contributes to the EU's strategy for growth and jobs' (EC, 2008).

Besides climate change and energy security it is clear that bioenergy can also contribute to rural development, and therefore, support agricultural producers around the world. Although not explicitly mentioned in the European Directive, this agricultural agenda is often seen as another important driver for specific policies on bioenergy (Aantjes, 2007).

The 'Renewable Directive' of the European Commission also contains a specific binding target for the transport sector of 10% of renewables compared to the final consumption of energy in the transport sector for each Member State in 2020. The way this target is formulated, makes it clear that biofuels are the only option to achieve this renewable target in the transport sector. The term 'biofuel' is used when bioenergy for the transport sector is meant. Bioenergy refers to all biomass used for energy production, including for transport, electricity and the heating and cooling sector.

At this stage, European Member States and the European Parliament are supposed to approve the proposals from the European Commission in a co-decision process. The leading Committee on Industry, Transport and Energy (ITRE) of the European Parliament recently agreed to differentiate targets for 2020 in a 6% target for conventional biofuels and 4% for advanced biofuels or other options of renewable transport (via electricity or hydrogen). In this way, the European Parliament introduces specific targets for so-called 1st and 2nd generation biofuels. First generation biofuels are made by conventional fermentation and distillation of sugar and starch (bioethanol) or using oil-containing crops to produce biodiesel. Biodiesel replaces diesel, while bioethanol replaces gasoline.

Second generation biofuels can be made from almost any form of biomass. If made from forest- or crop-residues, they do not compete directly with food for feedstock. Indirectly, it may compete with feed if residues were used differently before. Moreover, if made from dedicated energy crops, they compete for land and water resources (see also Chapter 2). Second generation processes are still at the pilot plant stage. Thermochemical processes ("biomass to liquids", BTL) work by gasifying ligno-cellulosic material then synthesizing road-fuel from the gas. The sub-units (gasifier, gas separation, Fischer-Tropsch synthesis to form biodiesel) already exist in other industrial processes: they only need integration. This means one can predict performance and cost, but scope for future technological improvement is limited (JRC, 2008). The cellulose-to-ethanol process is more innovative. Technology breakthroughs are needed to make it competitive, and these are unpredictable. It is uncertain whether these techniques are competitive in 2020 (see also Chapter 3).

2.2 Call for sustainability criteria

While the European Commission was working on detailed proposals for Directives following the targets set by the European Council in March 2007 (EU, 2007), a debate on the use of bioenergy and, in particular, biofuels developed in the course of 2007. From initial positive reactions, and even reactions that the targets were set too low (FOE, 2007), the debate focused more and more on the performance of biofuels with respect to sustainability. In 2007, the OECD published the report ‘Biofuels: Is the cure worse than the disease?’. The report concluded that food shortages and damage to biodiversity are a possible consequence of a rush on energy crops, without clear benefits, since the claimed greenhouse gas reduction effects can be very small (Doornbosch and Steenblik, 2007).

Righelato and Spracklen (2007) concluded that the carbon balance for reforestation is much better than for using first generation biofuels. And more recently, Fargione *et al*. (2008) and Searchinger *et al*. (2008) concluded that biofuels are increasing global greenhouse gas emissions, through land-use emissions because of deforestation. In their analyses, special attention was paid to the displacement effect of biofuels: energy crops may occupy productive land and other agricultural practices are shifting towards newly formed arable land at the cost of existing ecosystems. In different analyses different institutes stated that the 10% target should be reconsidered (OECD, 2008; RFA, 2008; Eickhout et al., 2008a).

In this way, the debate shifted the focus of the potential benefits of biofuels towards sustainability threats of biofuels. Sustainability aspects of biofuels were already of concern in national studies in the United Kingdom, Germany and the Netherlands. The Cramer Committee in the Netherlands composed a list of sustainability indicators, with focus towards global effects on local communities in developing countries. The topics addressed are (Cramer *et al*., 2007):

- Greenhouse gas balance: measured over the complete production chain, a greenhouse gas reduction of 30%, compared to use of fossil fuels, must be met in the transport sector.
- Competition with food and other local applications: production of biomass may not endanger the food production and other applications (for medicines et cetera).
- Biodiversity: biomass production may not affect protected or vulnerable biodiversity.
- Environment: quality of soil, air and water must be sustained.
- Welfare: production of biomass must contribute to local welfare.
- Well-being: production of biomass must contribute to the well-being of employees and local population.

From this list, it is obvious that not all topics of the Cramer Committee are translated into sustainability criteria in the proposal of the European Commission. For example, criteria on food security have not been established yet.

In its proposal, the European Commission formulated sustainability criteria with respect to the greenhouse gas balance and biodiversity impacts. As the Commission stated, consequences for Third World countries (especially regarding changes in commodity prices and negative effects on food security) will be reported on in 2012 and every two years thereafter. The Commission will base its report on reports from Member States, and on reports from relevant third countries, intergovernmental organizations and other scientific and relevant pieces of work. In its report, the Commission ‘shall, if appropriate, propose corrective action’ (EC, 2008). The European Parliament suggests adding social criteria to be met by producers and proposes to add an indirect land-use change component in the greenhouse gas balance calculations (EP, 2008). These propositions indicate that the debate on sustainability criteria will continue.

2.3 The debate on sustainability issues

The debate on biofuels is focused on issues of greenhouse gas balance, impacts on land use, including biodiversity, the potential competition with food and the relevance for development. These issues are introduced here.

Greenhouse gas balance

One of the most important reasons why targets for biofuels have been set by the European Union, is the expected mitigating potential of biofuels with respect to greenhouse gas emissions. Since the EU has set a climate stabilization target at 2°C all mitigation options to reduce greenhouse gas emissions should be considered. Scientific literature includes various estimates of the relationship between the concentrations of greenhouse gases in the atmosphere and temperature increase, and thus the chance that the global temperature increase will not rise above 2°C. Figure 1.1 shows the ranges of estimates given for various stabilization levels. This not only takes account of carbon dioxide (CO_2) levels, but also other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). The chances of keeping the temperature increase under 2°C improve considerably at lower CO_2 concentration levels. Figure 1.1 shows that at a stabilization level of 550 ppm CO_2-eq. there is a significant risk (at least 66%) of exceeding the 2°C limit. However, at a concentration level of 450 ppm there is a reasonable chance (over 50%) of achieving the 2°C objective (MNP, 2006; IPCC, 2007).

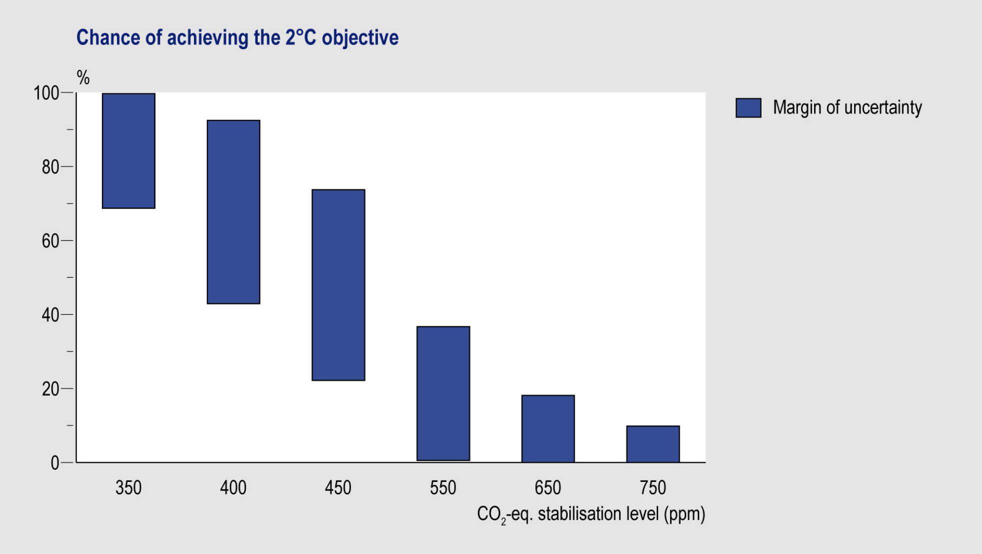


Figure 1.1. Estimates given in the scientific literature concerning the chances of achieving the European climate objective, at various stabilization levels for greenhouse gas concentrations in the atmosphere . Source: MNP, 2006.

This clearly sets the scene for several mitigation options that need to be considered to reduce greenhouse gas emissions (GHG). To calculate the greenhouse gas reduction of biofuels, several aspects of the production process need to be considered. The following elements might have a significant impact on the results whether biofuels will reduce greenhouse gas emissions:

- The assumed or actual crop yield;
- N_2O emissions which can be attributed to the production of the biomass crop;
- Emissions due to processes in the production chain;
- The use of by-products;
- The system boundaries of the Life Cycle Analysis method.

The fraction of GHG that biofuels save will vary greatly, depending on these elements. JRC (2007) was responsible for the methodology and biofuels data that are used by the European Commission (EC, 2008). According to this, most EU commercial processes save between 18 and 50% GHG emissions compared to fossil fuels. In their proposal, the European Commission states that the greenhouse gas reduction due to the use of biofuels, needs to be at least 35% (EC, 2008). The European Parliament is suggesting to raise these reduction obligations to 45% in the beginning, increasing till 60% in 2015 (EP, 2008).

However, if crops, which otherwise would be used for food or feed (inside EU or exported) are instead used for biofuels, the emissions in EU are unchanged, but there are indirect emissions due to farming for food/feed which is displaced outside EU. These indirect impacts can deliver totally different results for the greenhouse gas balance and even result in an increase in emissions due to biofuels (RFA, 2008). To produce biofuels, farmers can directly plow up more forest or grassland. Clearly, this will release much of the carbon to the atmosphere that was previously stored in plants and soils (Searchinger *et al*., 2008). The loss of maturing forests and grasslands also forestalls ongoing carbon sequestration as plants grow each year. The size of this impact is difficult to quantify, and therefore, is part of future research. Meanwhile, in European policies fixed emission factors will be used for some specific land-use transitions (EC, 2008)

Impacts on land use and biodiversity

Besides objectives for greenhouse gas reductions, the European Commission has also formulated sustainability criteria to prevent loss of valuable biodiversity and undesired land use changes (EC, 2008). In promoting the use of biofuels, two contrasting issues play a role in relation to biodiversity. On the one hand, biodiversity loss is less when climate change impacts are mitigated (IPCC, 2007). However, changes in land use due to cultivation of energy crops have a negative impact on biodiversity. (CBD/MNP, 2007). This is of interest for policy formulation because the EU has also agreed upon a halt of biodiversity loss by 2010 besides the climate target. These two targets ask for a careful consideration of the consequences of setting sustainability criteria for biodiversity and land use impacts.

Clearly, cultivation of bioenergy demands land, especially on the short term for production of biofuels with existing techniques. Without biofuels, the extent of cropland reflects the demand for food, feed and fibre. The assumption that 10% of the European transport consumption is provided by biofuels in 2020, demands for a biofuel production that is equivalent to 34.6 Mtoe or 1.45 EJ (EC, 2007). This demand for biofuels will be met in a world where other land-demanding commodities are also asked for. Therefore, the European Commission has introduced criteria to prevent these undesired land use changes, both from a carbon balance perspective and a biodiversity perspective (EC, 2008; Eickhout *et al*., 2008a).

Alternatively, degraded and abandoned agricultural lands could be used to grow native perennials for biofuel production, as it is presumed that this would not lead to loss of biodiversity and excessive emissions of GHG (Hoogwijk *et al*., 2005; Tilman *et al*., 2006; Smeets *et al*., 2007). Or farmers can divert existing crops or croplands into cultivation of energy crops, not directly causing land use change. Farmers may also try to boost yields through optimizing cultivation practices, such as improved irrigation, drainage and fertilizer (which have their own environmental effects) (Searchinger *et al*., 2008). It is heavily debated to what extent these different strategies can and will be practiced. Fargione *et al*. (2008) argue that if biofuels are to help mitigate global climate change, the biofuels need to be produced with little reduction of the storehouses of organic carbon in the soils and vegetation of natural and managed ecosystems. According to Fargione *et al*. (2008) diverse mixtures of native grassland perennials growing on degraded soils have yield advantages over monocultures, provide GHG advantages from high rates of carbon storage in degraded soils and offer wildlife benefits (Figure 1.2). However, the use of these lands is an important scientific uncertainty. And certainly, these lands will have lower crop yields, therefore demanding more land. Searchinger *et al*. (2008) assume that positive and negative effects on agricultural yields, caused by bioenergy production, will balance out, implying that land replacement will be the dominant strategy. According to their model-based analysis, the dedication of 12.8 Mha US farmland to energy crops (maize) could produce 56 billion litres biofuel, but would in turn bring 10.8 Mha of additional land into cultivation, in the USA and for the most part elsewhere to replace the declined US agricultural exports. Searchinger *et al*. (2008) argue that the carbon emissions, due to such replacement of farmland, would exceed (cumulative) carbon savings from corn based ethanol for a (very) long period, exceeding 100 years. This period of carbon debt can even exceed 400 years in case of palm oil production in peat rich soils in Indonesia, and be as low as 20 years for sugarcane expanding into Cerrado grasslands in Brazil (Figure 1.2; Fargione *et al*., 2008). In a review of the paper of Searchinger *et al*. (2008) for the British Gallagher review, it was concluded that the basic issues raised by Searchinger are relevant, but that EU biofuel initiatives are fundamentally different from the US bio-ethanol initiative in that no fixed crop technologies are proposed. Therefore, 'it must be concluded that the Searchinger approach involves a high level of uncertainty, to the extent that its specific conclusion should not be regarded as safe' (ADAS, 2008). Nevertheless, it clearly shows that it remains eminently feasible that effects of biofuels on indirect land use change could be significant in relation to intended GHG savings. Therefore, the debate on indirect land use effects of biofuels is here to stay, for a while.

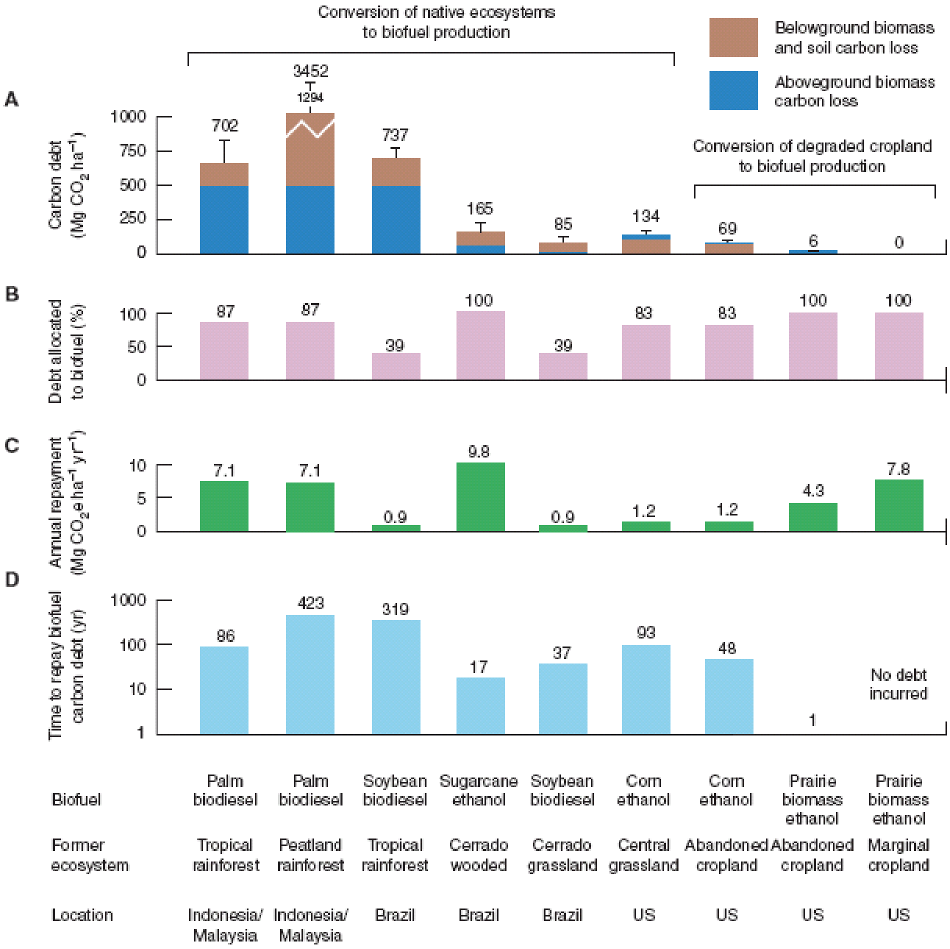


Figure 1.2. Carbon debt, biofuel carbon debt allocation, annual carbon repayment rate, and years to repay biofuel carbon debt for nine scenarios of biofuel production. (A) Carbon debt, including CO_2 emissions from soils and aboveground and belowground biomass resulting from habitat conversion. (B) Proportion of total carbon debt allocated to biofuel production. (C) Annual life-cycle GHG reduction from biofuels, including displaced fossil fuels and soil carbon storage. (D) Number of years after conversion to biofuel production required for cumulative biofuel GHG reductions, relative to the fossil fuels they displace, to repay the biofuel carbon debt. Source: Fargione et al., 2008.

The impacts on biodiversity are very much dependent on the type of land that is used for the biofuel production (CBD/MNP, 2007). Clearly, intensive production of biofuels is directly affecting biodiversity in a negative way, unless already intensively managed arable land is used (Figure 1.3). The positive impact of biofuel production through avoided climate impacts, is affecting biodiversity only after many crop rotations (up to more than 100 years, depending on uncertainties in the climate sensitivity). Therefore, the first years of production are dominated by the negative effect of land use. In the following years, the positive effect of avoided climate change gets more important with each harvest cycle, as it has a cumulative effect. When natural habitats (whether grasslands or forests) are used for biofuel production, the negative effect of land use change continues to dominate the positive climate change effect, even up to 2100 (Figure 1.3). At the extreme opposite side, biofuel production on recently abandoned lands that were under intensive agricultural management will immediately result in positive effects, as the former land use does not present valuable biodiversity (Figure 1.3).

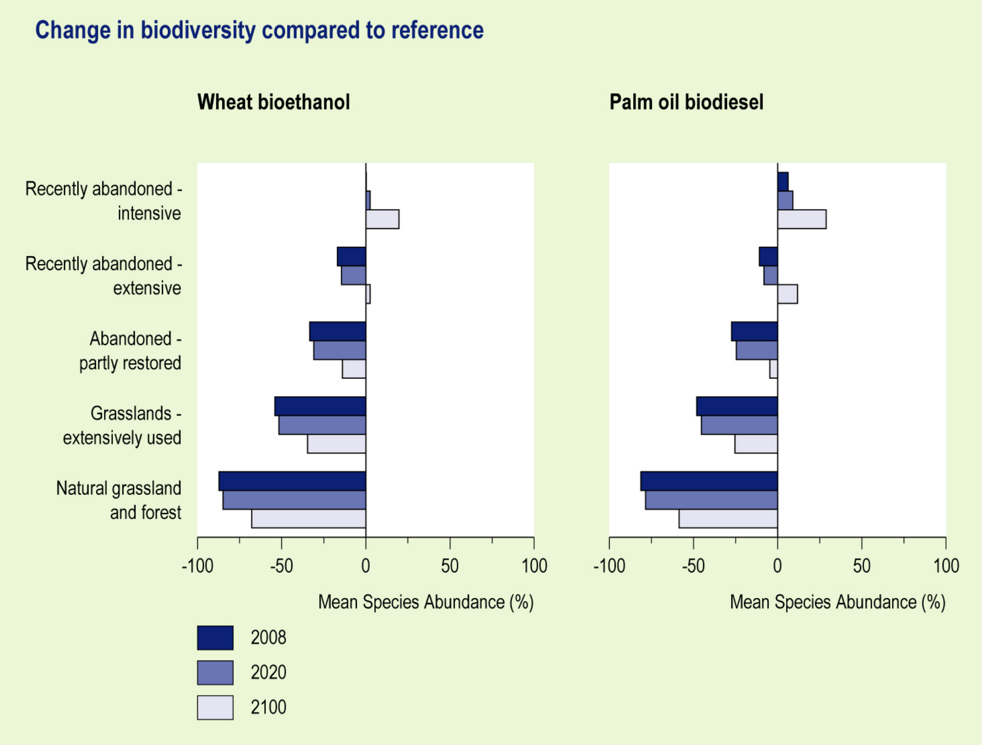


Figure 1.3. Biodiversity balance of land-use change and avoided climate change for wheat production (left panel) and palm oil production (right panel) Source: Eickhout et al., 2008a.

Competition with food

Another debated impact of the push for biofuels is its impact on food security. From a socio-economic perspective, large-scale development of bioenergy can be perceived as the unfolding of a new branch of (agro-)industry, respectively production chain. A renewable source of energy captures a share in the energy market, at the expense of traditional sources of energy. This bioenergy industry may develop as an additional economic sector, creating new opportunities for employment, income generation, export et cetera. But, as far as scarcity of resources (land, labor, capital) exist, it may also crowd out other economic activities, resulting in displacement effects and smaller net benefits.

Large-scale production of bioenergy may affect prices, especially prices of production inputs. Prices, paid by bioenergy producers for feedstocks – including inputs thereof like labor and land – may set price trends for other sectors, using the same feedstocks or inputs. This mechanism will be most effective for feedstocks, which are suited for energy production as well as for food supply. Many so called first generation bioenergy feedstocks – like sugar cane, soybean, rapeseed and palm oil – belong to this category. All reviewed literature agrees that the implementation of biofuel policy will lead to increased commodity prices (Eickhout *et al*., 2008a), although the various authors give different effects, partly due to differences in calculated situations.

On this point, differentiating between short-term and long-term price effects seems meaningful. Analyses, based on agro-economical modeling by the FAO and others, predict that in the long run prices of first generation bioenergy feedstocks will reflect energy prices (supposing that bioenergy production continues its growth towards a substantial market share). However, these analyses assume perfect market substitutions, which is not the case when policies are implemented to stimulate biofuels through blending obligations of fixed targets.

Theoretically, price transmissions to other food markets could result in a structural, but limited rise of real food prices. Structural, because the bioenergy application sets the marginal price and so breaks through the downward tendency, which dominated food prices since the 1970s. But also limited, because bioenergy production becomes uncompetitive (and public willingness to clear off cost increases will fall short) if food prices rise too much; after which the feedstocks involved will become available again as food supply and their prices will fall. In short: application as bioenergy feedstock creates a floor, as well as a ceiling for agricultural prices (Schmidhuber, 2006). The factual price development in the world sugar market supports this analysis (Figure 1.4). Again, this mechanism is not applicable anymore when fixed targets are implemented, since this market mechanism is disturbed by these fixed targets.

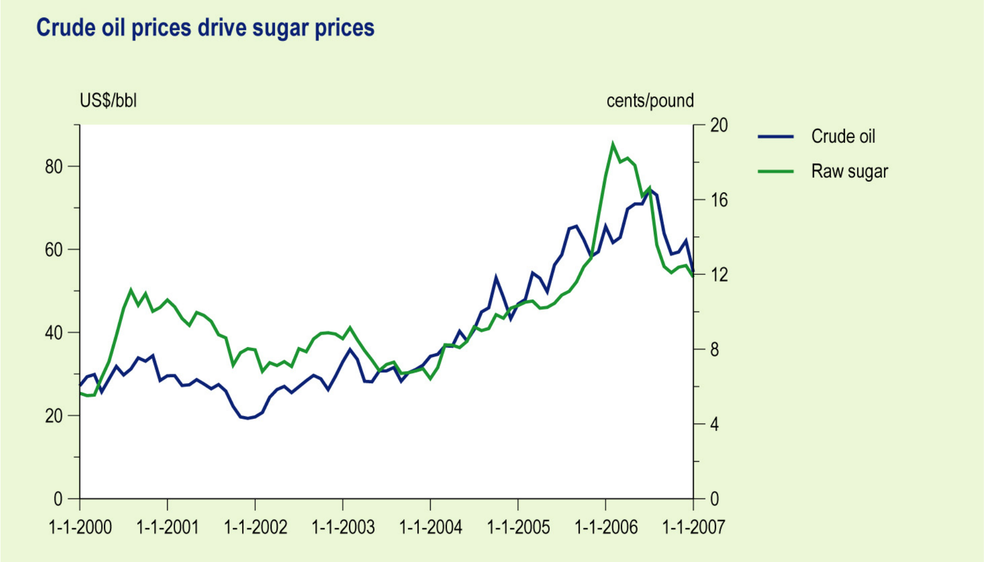


Figure 1.4. Sugar prices track crude oil price above US$35/bbl. Source: Schmidhuber, 2006.

In the short run numerous additional factors influence agricultural prices, like autonomous price volatility (e.g. caused by weather conditions and by increasing market liberalization), the sometimes explosively booming feedstock demand for bioenergy and delayed responses on price signals by feedstock – and bioenergy – producers (leading to cyclical periods of under- and overinvestment). Vigorous price fluctuations around the structural tendency may result from this. Moreover, the fast rise in world maize prices since 2004, due to rapid growth in bioenergy demand in the US, coincided with poor harvests worldwide and with a period of price recovery after historically low cereal prices around the year 2000 (Fresco, 2007). Clearly, biofuels add an additional pressure on this market. The exact role of biofuels in the increasing food prices is uncertain, although contributions of 30% have been calculated (Rosegrant *et al*., 2008). Mitchell (2008) even concluded that biofuel policies have played the most important role in increasing food prices estimated at 80%, since other increases would have had a more moderate influence than now with the biofuel policies in place. Mitchell (2008) acknowledges that his approach is different from other studies. This shows the uncertainties and unknowns in economic apportionment studies that still exist.

Relevance for development

Large-scale development of bioenergy creates opportunities for employment, income generation, export et cetera, but may also crowd out other activities as a result increased scarcity of resources (land, labor, capital) resulting in displacement effects This may include conversion of small scale and diverse farming practices into large-scale, mono-cultural agribusinesses, creating an imbalance in wealth distribution. Large-scale production of bioenergy will affect prices, especially prices of production inputs. Prices, paid by bioenergy producers for feedstocks – including inputs thereof like labor and land – may set price trends for other sectors, using the same or similar feedstocks or inputs.

The direct result of higher food prices is loss of purchasing power for net buyers of food and gain of purchasing power (extra revenues) for net sellers. On the level of countries, this result translates into an improved (worsened) trade balance for net agricultural exporters (importers). Within countries, in general benefits are to be expected for rural families, disadvantages for urban families. Within each group, advantages and disadvantages may be unevenly distributed. E.g. in some countries, notably in Sub-Sahara Africa, most rural households are nowadays net buyers of food. High food prices affect households differently, depending on their production and consumption patterns and what commodities are produced and consumed, the share of household income dedicated to food, and the degree to which world prices are transmitted to local markets. High food prices can also affect different groups within households differently. A large body of research on structural adjustment and on the Asian and Mexican economic crises shows that shocks have affected women disproportionately, suggesting that the current food crisis may have analogous impacts on female consumers and producers (Quisumbing et al., 2008).

Income generation within the bioenergy sector, in combination with higher food prices, may well have indirect impacts. Improved profitability in the agricultural sector may trigger investments to expand and intensify production. The FAO values such dynamics as a potential for revitalization of rural areas: bioenergy may work out as a booster of a global ‘renaissance of agriculture’ with overall positive effects on poverty reduction and food security (Schmidhuber, 2006; OECD/FAO, 2007). Materializing this optimistic perspective, however, depends on many factors and actors. Will investments follow a steady path or cycles of boom and bust? Are big landowners and international concerns or small holders/co-operatives leading the development? Does output growth result from extending agricultural area or from productivity gains on existing area? From labor-intensive, capital- and technology-saving production methods or from the opposite? Will it supersede the traditional use of natural assets (ecosystem services), especially by the rural poor? Will regional unbalances, caused by bioenergy sector growth and/or shrinkage in other sectors, provoke interregional dynamics like migration or shifting food balances? Do the rural poor have the capacity to invest? Are there any institutional constraints (such as land title) preventing the poor from benefiting? These aspects have hardly been part of research so far and, probably, monitoring efforts can only shine some first light on these aspects in the near future, but only after they have taken place (Eickhout *et al.*, 2008b; see also Chapter 5).

2.4 Scientific research on biomass availability for biofuels production

Because of this increased political attention to biofuels, many scientific studies have been released the last few years. In these studies, two main approaches can be distinguished: 1) studies focusing on potential availability of biofuel feedstock and 2) agro-economic studies focusing on meeting specific biofuel targets. Both approaches are introduced here.

Potential studies

Potential studies usually focus on production chains of biomass, with analyses of expected productivities, land availability and costs estimates. These studies do not focus on implementation of policy goals, but show what the potential of biofuels may be. Lysen and van Egmond (2008) give an overall summary of potential studies that are available.

Potential studies for the short-term (2020) are less abundant. Best examples are work of EEA (2006) and the REFUEL-project (Deurwaarder *et al.*, 2007) but they have only analyzed the situation for the EU.

The European Environment Agency’s (EEA) estimated the potential availability of feedstock within the European Union (EU-25; still without Romania and Bulgaria) for bioenergy from agriculture, waste and forestry. By taking a number of environmental conditions into account these potentials are considered to be environmentally-compatible (EEA, 2006).

The REFUEL assessments (Deurwaarder *et al.*, 2007) analyzed European production and consumption of biofuels. For estimating feedstock potentials, EU27, Switzerland, Norway and Ukraine were grouped. Imports from other countries were not considered. The study includes a full-chain assessment of costs, including cost developments over time due to improvements in agriculture and technology learning.

Strengths of these kinds of studies are the extensive analyses of impacts of assuming different levels of crop productivities, technological opportunities and the integrative approach of land availability. In this approach several sustainability criteria like direct and indirect land use and greenhouse gas balance are explicitly accounted for, since undesired land use is excluded beforehand. Clearly, this is only true for the geographical level of analysis: EEA and REFUEL only looked at land use changes within Europe and not at possible displacement impacts outside Europe. Other clear weaknesses of these approaches are the lack of analyses of economic mechanisms and, more important, the lack of consideration of issues that are involved once market mechanisms are implemented. Markets aim for cost minimization, which is not always realized on the locations that have been identified by the potential studies as environmentally preferred options, like marginal lands. Moreover, import or export flows of biofuels are based on assumed availabilities of biomass in the different regions. Therefore, results on import or export of biofuels are driven by assumptions and do not reflect market mechanisms.

Agro-economic studies

Another approach is to use agro-economic models that focus on economic mechanisms that will lead to introduction of biofuels in different markets. Cost minimization is usually driving these model results. Dependent of trade assumptions and other price determining factors like labour, capital and land, these models will deliver commodity prices, production levels per region and sector and the amount that is being traded between regions. Well-known examples of these kinds of studies are work of OECD, IFPRI, WUR-LEI and World Bank, of which the first three studies will be discussed in Chapter 5.

Strength of these approaches is the economic consideration that is implemented and the relation with specific biofuel targets that can be made. However, these studies usually do not consider sustainability criteria. Moreover, technological improvements are usually driven by assumptions on elasticities that are very uncertain, especially for new techniques like second generation biofuels. Elasticities are usually not suited for new technologies. Elasticities are capable to analyze shifts from existing technologies that are comparable of volume. New, not existing technique must come from zero, and therefore very high elasticities are needed, that are generally underestimated in economic models, hampering the introduction of new technologies.

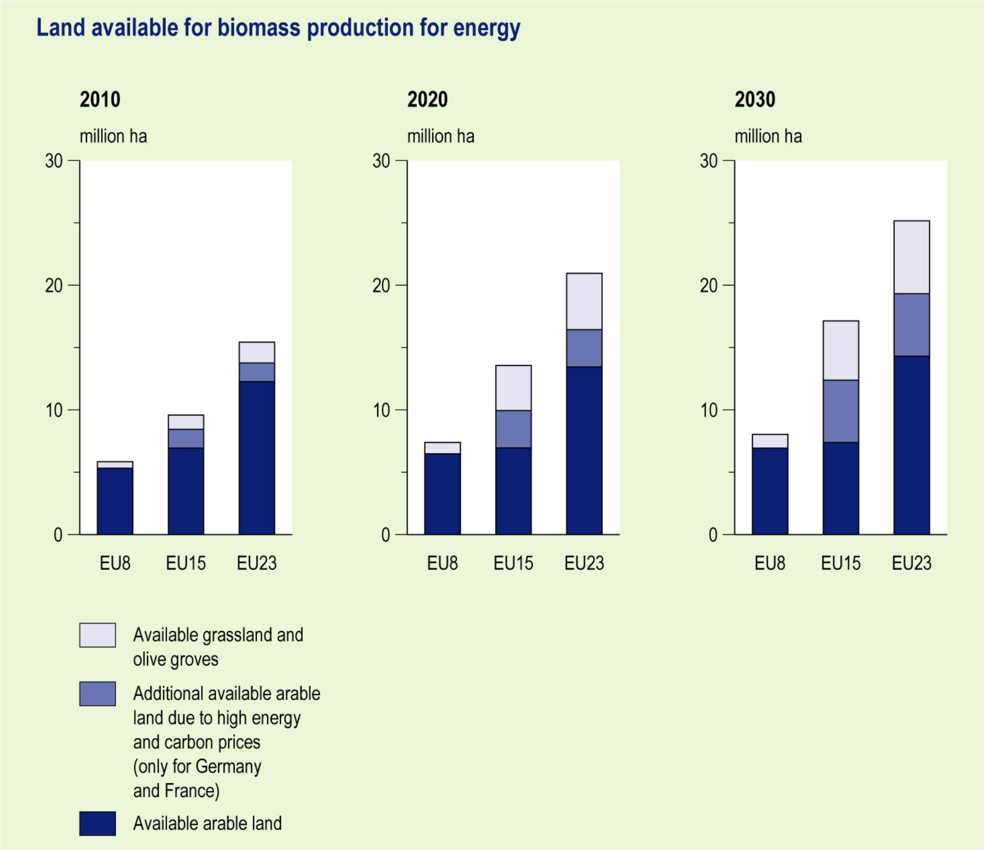


Figure 1.5. Projected land released from agricultural use within Europe that can be used for biomass production. EU23 refers to the 25 European Member States in 2004, except Malta and Cyprus. EU8 and EU15 are subtotals, comprising accessed countries from Central Europe in 2004 and the 15 'old' Western European Member States, respectively. Source: EEA, 2006.

2.5 Results from existing studies

According to the European Environment Agency on European potentials (EEA, 2006), the amount of agricultural land in the EU23 that can be used for bioenergy production amounts up to 16 million hectares by 2020 (Figure 1.5). This land can be found in both Central and West European countries, mainly in Poland, Spain, Italy, the United Kingdom, Lithuania and Hungary. Germany and France are expected to release substantial areas due to the competition effect of bioenergy production versus food/feed production for exports (EEA, 2006). The potential available land is made up of arable land released from food and fodder production, and land that is released through productivity increases. In the EEA study, even specific biodiversity criteria are considered (EEA, 2006). This study is the basis of many assumptions that all bioenergy can be produced within the EU. In the EEA study, countries without any available agricultural land are generally those with intensive or very competitive farming systems. High biodiversity grasslands are excluded, as they are valuable for important elements of (agro-)biodiversity (habitat for meadow birds,, species rich swards et cetera). The applied land-use criteria are comparable to those in European Commission's proposal. More land may be available when grasslands and olive groves are taken into account, but these probably do not qualify under the presently proposed criteria (EEA, 2006; Figure 1.5).

EEA concludes that 'significant amounts of biomass can technically be available to support ambitious renewable energy targets, even if strict environmental constraints are applied'. However, these potentials are valid for bioenergy in general and not for biofuels specifically. The REFUEL study looked at the European potential for biofuels specifically, including Ukraine, which contributed one third to the total potential estimated by REFUEL. From these potential studies it can be concluded that, potentially, all biofuels can be grown within Europe. However, these studies have not looked at market mechanisms influencing producer decisions (as described in Section 1.4).

Macro-economic studies like, OECD-FAO (2008) and Banse *et al*. (2008) do work with agro-economic models, considering market mechanisms. These studies show that imports of biofuels will occur to meet the biofuel target of 10% in 2020. The LEI study projects imports of 50% (Banse *et al*., 2008). The most important factors determining these model outcomes are the assumed contribution of second generation biofuels (none in the LEI study) and the question what will happen with Common Agriculture Policies (LEI-study assumes full liberalization). This clearly shows that biofuel policies cannot be regarded without agricultural policies and the uncertainties around new technologies like second generation biofuels. These issues are discussed further in the following chapters.

3 Agriculture and natural resource use

3.1 Introduction

Ultimately, all biofuels are derived from plant biomass, but for a reflection on the impacts of biofuels on social, environmental and economic developments, a distinction in biomass feedstock is necessary. Feedstock for biofuels can be obtained from biomass residues that are already part of current ecosystems or production chains, e.g. residues in forest or waste in the food and feed industry. Diversion of residues for biofuel production will have ecological and economic implications for these ecosystems and chains. The other source of feedstock for biofuels comes from food/feed crops (1st generation biofuels) and non-food crops, like wood and Miscanthus (2nd generation biofuels). These crops, purposely grown for the provision of feedstock for biofuels, put a claim on natural resources, especially land, water and nutrients, and may therefore compete with other functions for which these resources are used.

This chapter reviews developments in agricultural productivity and related natural resource use and the use of residues for the production of biofuels. Only the availability of residues that are used as input for agricultural fields, like compost and straw, are discussed. One of the major reasons for biofuel production is, to mitigate climate change through the reduction of greenhouse gas emissions. Therefore, any impact on agriculture and land use change should be evaluated at the global scale. At the same time however, policies, strategies and studies are implemented at regional scales such as the EU, USA, Southern America and so forth and have been considered in this review also.

3.2 Agricultural productivity

The expected increase in agricultural productivity is a critical variable in all analyses. In agricultural sciences, the search for enhanced productivity relates to all production factors, i.e. land, water, nutrients, labour, capital and so forth, and also includes climatic conditions, which makes it difficult to predict future yields. However, any sensible analysis of productivity increase in agriculture should take basic principles of production ecology into consideration. Plant production is a result of many plant growth processes and is affected by the interaction of plants with the biotic and abiotic environment. At the same time, much knowledge has been gained over the past decades in this regard. Figure 2.1 serves as a simple illustration of the production-ecological principles.

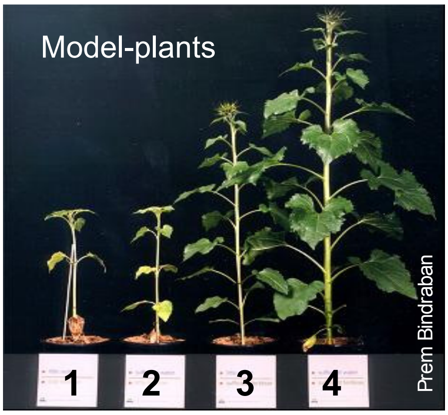


Figure 2.1. The effect of water and nutrients on plant growth (Own experiments P.S. Bindraban).

Pursuing a production ecological approach is essential because of the strong interactions between production factors. Plant 1 is grown in a poor unfertilized soil with little water and remains small. Adding water would be expected to improve growth, which is not the case as the poor soil fertility puts a stronger limit to its growth (plant 2). Adding fertilizers rather than water does enhance growth indicating that the strongest limiting production factor (i.e. nutrients) was eliminated (plant 3). At the same time this third plant shows that water is used more efficiently under these fertilized conditions as the same amount of water was applied as in plant 1. Adding both nutrients and water boosts growth to a level where neither of these factors is limiting but where other factors, like radiation, set a ceiling to growth (plant 4).

The assumed future increase in crop yields is a key variable in all studies that estimate biofuel production potentials. It is likely that yields of most crops increase further in the near future, but simple (linear) extrapolations from past trends do not take underlying mechanisms and driving forces into account that have caused the yield increase. A complex interaction between agro-technical and institutional settings have in the past lead to significant yield increases, even causing entire transitions with drastic yield increases (Lee and Tollenaar, 2007). It should however be carefully assessed whether these underlying driving forces remain valid in future. The agro-technical aspects can be distinguished in breeding and agronomic innovations and will be described by means of the schematic presentation in Figure 2.2.

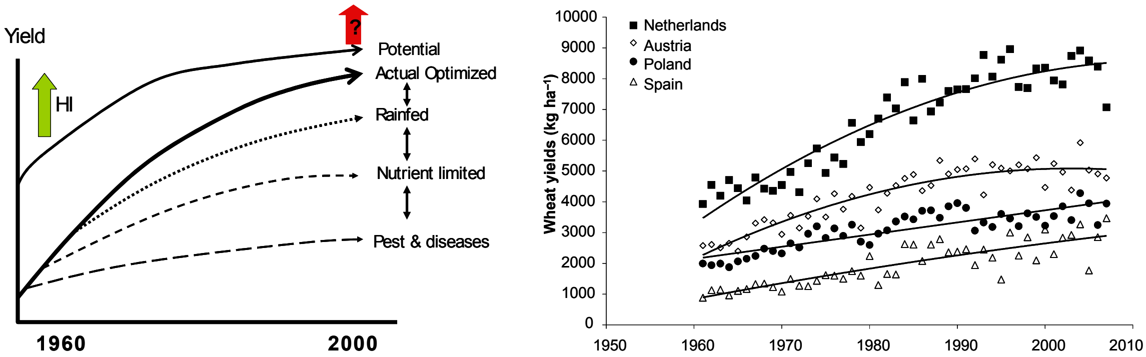


Figure 2.2. Schematic presentation of options to increase crop yields (left) and observed wheat yields in several European countries (right). Based on FAO data. See text for explanation.

The increase of the genetic potential of major food crops during the 1960s to the 1980s has given a boost to the yield increase in the past, primarily because of the increased harvestable fraction of the crops (HI; see Figure 2.2, left side). The genetic yield potential is not uniform across the world, as it also depends on the biophysical conditions of the sites where crops are grown. Apart from genetic potential, crop production is also strongly determined by the availability of water and nutrients, while it can be reduced by pests and diseases or competition with weeds. All these factors interact and occur simultaneously and have different impacts on yield. According to Sayre *et al.* (2006) the abilities to further enhance the potential yield level has decreased to virtually nil, while little gain is being reported for other crops, like rice. However, there is still a lot to be gained by bridging the gap between actual and potential yields in many countries, but countries/locations differ widely in their possibility to increase crop yields and the efforts that are needed. Examples from Europe show that on average in the Netherlands and in Austria wheat yield increase was not observed after 1990 although a linear regression from 1960-2007 would suggest a significant increase up to 2007 (Figure 2.2, right side with wheat as an example). In Spain, a yield increase has clearly been achieved on average until 2007, but at a much slower rate as compared to the Netherlands and Austria. The slower development in Spain is caused by the harsher biophysical environment (drought conditions) that hampers the rate of increase. The trends of Europe can also be found at a global level, where higher yield gains have been obtained under favourable biophysical and institutional conditions with high external inputs of production means, while yield gains have been disappointing under less favourable conditions (e.g. Figure 2.3). The potential to increase yields under less favourable conditions can indeed be high because of the large yield gap (e.g. Bindraban *et al.*, 2008), but closing these gaps is however subject to many constraints (environmental, biophysical, socio-economic, etc.), some of which may be prohibitively costly to overcome. This will be further explained under the various production factors later in this chapter.

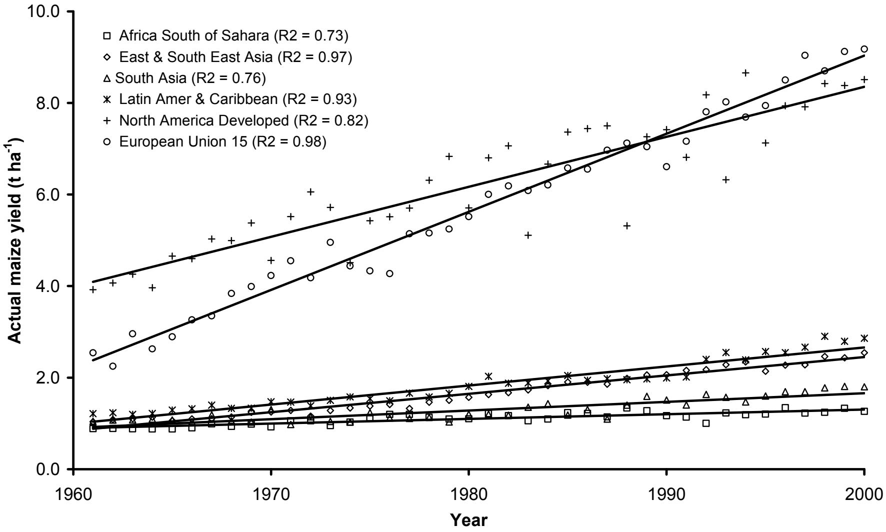
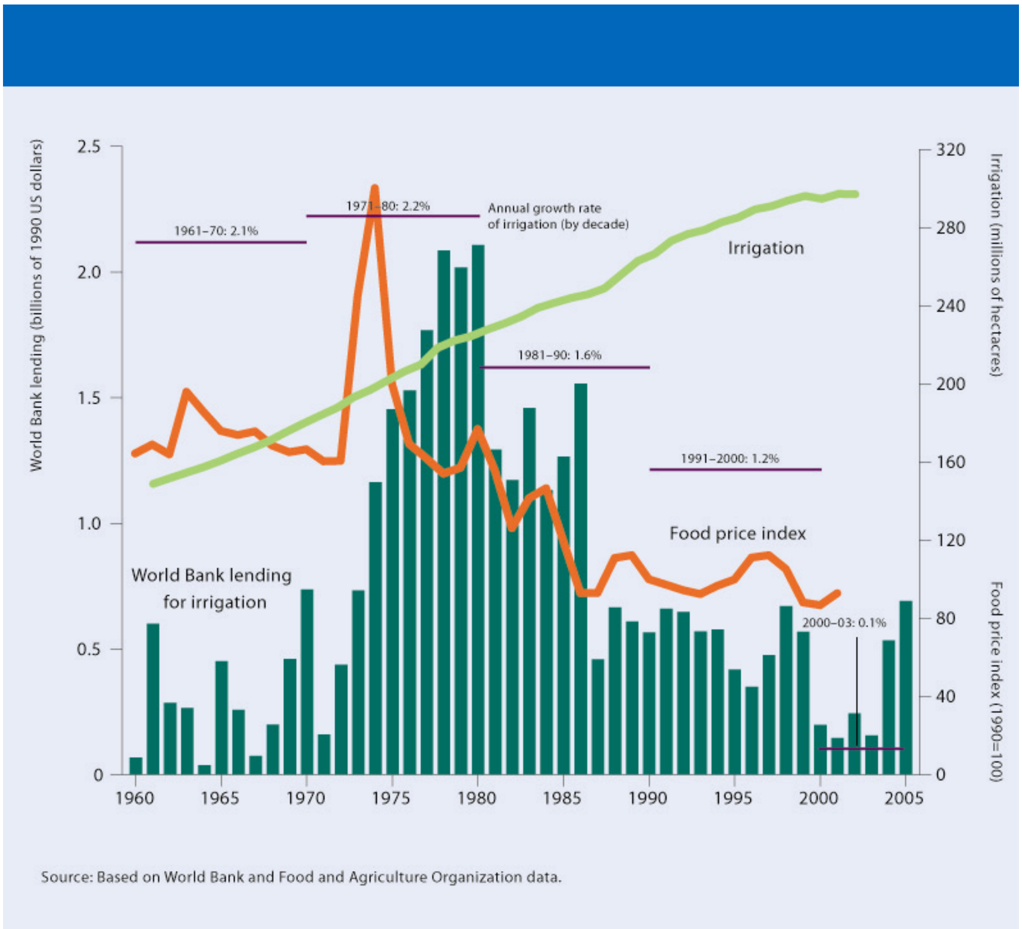


Figure 2.3. Yield increase over the past four decades in 4 global regions. Source: Bindraban et al., 2008.

By far the largest increase in crop productivity in the past decades, primarily during the 1960s to the 1980s, has been obtained in the rapidly expanding irrigated areas. Along with increased fertilizer inputs and use of biocides to control pest and disease and weed pressure, yields are typically two to four times higher under irrigation than under rainfed conditions, so that irrigated acreage of 19% of the arable land provided 40% of total food supply in the world. Further gains in “crop per drop” are indeed feasible, i.e. by using less water for the same or slightly higher yields, but generally with a much smaller improvement of yield per land area (Van Dam, *et al.*, 2006; Bindraban *et al*, 2006a). The era of rapid expansion of public irrigation infrastructure is over (Figure 2.4, from Molden, 2007), because of the increasing social and environmental concerns related to large scale irrigation schemes and the limited availability of sweet water. Public investments in the past have been high and gave a boost to irrigated agriculture, especially with the introduction of small scale pumping by farmers. However, it is increasingly leading to depletion of groundwater resources (Molden, 2007). The expansion of the irrigated area has been declining from over 2% during the 1960s to the 1980s to less than 1% today.

Yield gains have been far less under rainfed conditions. Variability in yield due to erratic rainfall also dampens investments in other inputs such as fertilizers because of the higher investment risks. Yield improvements during the 1960s to the 1980s have come mainly from the increase in yields under favourable conditions, including irrigation. Recently, more emphasis has been placed on improving yield ability of crops under rainfed conditions by introducing drought tolerance, but progress is much less, because more targeted breeding is required (Bindraban, 2006b, Bennet, 2003)

Another reason for obtaining high yield levels in the past has been the availability of fertile lands. Over time, part of the most suitable fertile lands is being occupied by growing cities and other hard infrastructure (Brown, 1995), while land is turned into nature in various OECD countries. Consequently, land expansion is increasingly occurring in current less suitable soils that need larger amounts of inputs to correct for adverse conditions, such as high amounts of lime and phosphorus in the Cerrado in Brazil (Elbersen *et al.*, 2008).



Source: Based on World Bank and Food and Agriculture Organization data.

Figure 2.4. Development of World Bank lending for irrigation, food price index, world irrigated area and percentage annual growth rate of irrigation. Source: Molden, 2007.

Marginal and degraded lands in combination with non-food crops are put forward to inherit large potentials for biomass production (e.g. Hoogwijk *et al*., 2005). These lands are however not unambiguously defined (Smit *et al*., 1991), which currently leads to classification of biophysically favourable environments as marginal, or secondary forest as degraded (Elbersen *et al*., 2008). In any case, marginal lands are generally beset with a range of biophysical limitations, such as low and variable rainfall often with prolonged periods of drought, poor soil quality in terms of fertility, texture and structure and occasionally yield depressing or toxic conditions such as high salinity, high levels of aluminium or iron, etc. Also, unfavourable socio-economic conditions lead to low levels of intensification and capitalization of farming operations and may reduce opportunities for productivity enhancing measures, e.g. in cattle ranging in Latin American countries (IBGE, 2007; CNPC, 2008). In short: marginal lands give marginal yields. These limitations cast serious doubts whether realization of the estimated potentials of marginal and degraded lands is possible within the coming decade(s).

Without a production-ecological approach that estimates the effect of local conditions on production possibilities and without an assessment of the underlying driving forces that can make the necessary resources for production (increase) available in the future, it will not be feasible to accurately estimate where the production will level off, what the costs will be in terms of necessary investments and whether the rate increase from the past can be extrapolated to the future.

Projected yield increase

Projected yield increase is discussed in all studies while quantitative information is given in varying level of detail. Accurate insights in the estimation procedures of both yield and demand projections are important for predictions of land use changes. There is clearly much debate about the projections of yield increases. The OECD-FAO (2008) states for instance: “historical trends in technology growth are assumed to continue into the medium-term future and developments of decreasing yields (weather-related) or increasing relative to the historical trends (through additional innovation) are not discussed nor assumed here”. Hence, OECD-FAO assumes positive developments (higher increase than historic trends, due to higher prices and technological innovations), and negative developments relative to historic trend (e.g. by insecure weather conditions like climate change and increased use of less fertile lands), to balance out. IMPACT (see Rosegrant et al., 2001 for background) and LEITAP (see Nowicky et al., 2006 for background) use a price-response relation in addition to the future trends from the FAO. By estimating future prices, yield increases are determined and superimposed upon the trend. With higher crop prices in the future a higher yield increase is used in the study of LEITAP as compared to the FAO. LEITAP also takes possible adverse conditions due to climate change into account, but not all studies have been explicit on this matter.

According to FAO prognosis, world increase of crop productivity per annum varies from 1.1% (rice) to 1.6% (horticulture), see Table 2.1. Differences in rates of yield increase significantly affect land area requirement to meet demand as has been elaborated in section 2.4.

Table 2.1. FAO prognosis for land productivity (% change per year from 2001 to 2030); based on pers. comm. Bruinsma, see also Bruinsma, 2003.

	EU15	CEEC_EU	USA	Oceania	E_Asia	SE_Asia	S_America	M_Africa	S_Africa	World
Rice	0.67	-0.23	0.83	0.20	0.93	1.10	1.57	2.40	3.47	1.10
Grains	1.17	0.60	0.73	1.40	1.60	1.40	1.53	2.13	1.60	1.17
Sugar	0.93	1.10	0.67	0.73	2.80	1.13	1.13	2.13	0.60	1.33
Oils	0.40	0.90	2.63	1.03	1.30	0.97	1.10	2.43	2.03	1.23
Horticulture	0.50	0.60	1.30	1.20	2.80	1.83	1.30	1.77	0.73	1.60
Other_crops	0.60	1.17	1.57	1.73	2.20	0.80	1.00	1.97	1.50	1.50
Cattle_SG	0.40	0.00	0.20	0.37	1.50	2.77	0.87	2.97	1.40	0.77
Pigs_poultry	0.17	-0.30	0.97	0.63	0.43	2.33	1.33	3.37	1.07	0.40
Dairy	0.20	0.10	0.33	0.87	1.53	3.50	0.57	1.23	0.60	0.23

The EEA study (2006) has used another source for their yield growth estimations in the EU (see Table 2.2). Comparison reveals for instance that yield increase of grain crops is much lower in EU15 (Table 2.2) of the EEA study than in the FAO prognosis (FAO: ca. 1.2% and Table 2.2: ca. 0.4 – 1.0%), while oil crops show opposite expectations (FAO: ca. 0.4% and Table 2.2: ca. 0.5 – 1.4%).

In the REFUEL study (Fischer et al., 2007), another approach was used. For EU15 they used an extrapolation of historic trends based on FAO statistics, but for EU10 it was assumed that in 2050 the yields of both EU parts would converge, meaning that EU10 would have reached the production level of EU15 by then. For the crops growing in EU15 an increase of 0.8% per annum was applied which is in the range of the data from the FAO (between 0.4 and 1.2%), but for EU10 the assumed increase in growth amounts to 2.2% which is significantly above the values given by the FAO for CEEC (highest value equals 1.2%) and by the EEA (beyond 2011 most values around or below 1%; Table 2.2). Other estimates for cereal yield increases are given in Figure 2.5, which are again different from the studies above.

Table 2.2. Expected crop yield increases from the EEA report (2006.)

Table I-1 Yield increase of the Animlib scenario in the original CAPSIM model

	2000–2011	2011–2020	2020–2025	2000–2011	2011–2020	2020–2025
		EU-8			EU-15	
Soft wheat	-	0.58 %	0.76 %	-	0.57 %	0.98 %
Durum wheat	2.58 %	1.68 %	– 6.33 %	1.03 %	0.67 %	0.48 %
Rye and meslin	1.19 %	0.54 %	0.82 %	0.71 %	0.57 %	0.83 %
Barley	1.34 %	0.83 %	1.07 %	0.84 %	0.63 %	0.84 %
Oats	1.34 %	0.96 %	0.84 %	0.54 %	0.44 %	0.40 %
Grain maize						
Other cereals	3.94 %	2.60 %	0.59 %	0.73 %	0.40 %	0.71 %
Paddy rice						
Pulses	1.02 %	0.33 %	0.33 %	0.97 %	0.15 %	0.12 %
Potatoes	1.77 %	1.16 %	1.16 %	0.47 %	0.35 %	0.69 %
average sugar beets A-C	-	-	-	-	-	-
Rape and turnip rape	0.20 %	0.37 %	0.39 %	1.40 %	0.70 %	0.98 %
Sunflower seed	0.65 %	0.76 %	– 0.50 %	0.51 %	0.70 %	0.96 %
Soya beans	3.99 %	2.58 %	1.19 %	1.05 %	1.03 %	0.83 %
Vegetables	0.27 %	0.27 %	1.14 %	1.14 %	– 0.79 %	– 0.05 %
Fodder maize	2.45 %	0.96 %	0.51 %	0.66 %	0.58 %	0.75 %
Grass-grazing	– 2.01 %	0.62 %	– 3.31 %	– 1.25 %	– 0.64 %	– 0.89 %

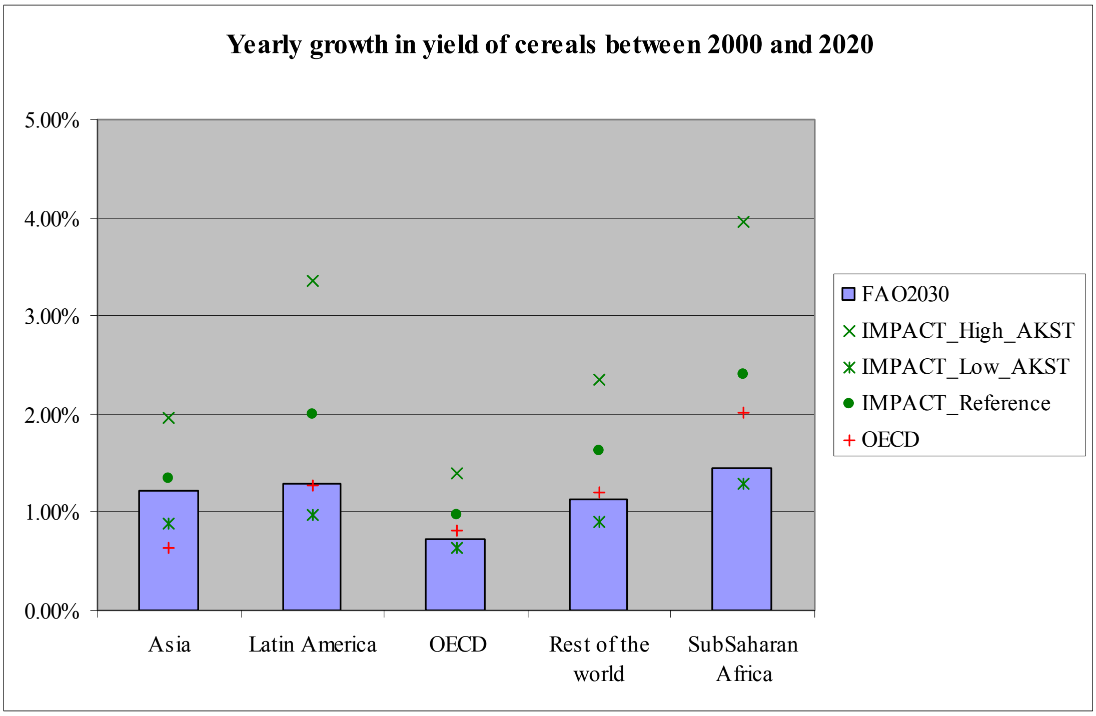


Figure 2.5. Estimated cereal yield increase in various regions of the world until 2020, according to different assessments. For details about legends see http://www.agassessment.org/. *Source: Kok et al., 2008.*

3.3 Agricultural demand

To be able to reflect on the need for production increase in agriculture, a quick review of the demand for food, feed and fuel is outlined here.

The diet composition is of critical importance in calculating the food/feed demand and resulting claim on natural resources which differs greatly between diet commodities. Animal products put a larger claim on these natural resources, if the resources used to produce the animal feed can also be used for the production of crops that can be consumed directly. Some studies have modelled future diets as a function of socio-economic developments (e.g. OECD-FAO Outlook, IMPACT, LEITAP), differentiating for countries/regions in the world. The OECD-FAO outlook for instance, predicts an increase of per capita meat consumption of 0.8 and 1.0% per year in developed and developing countries respectively and assumes an annual increase in world milk production of 1.8% for the near future. REFUEL however extrapolates historic trends of per capita consumption, with a decline in consumption of ruminant livestock products in the EU15, while consumption of other livestock increases. For the EU12 the ruminant consumption was kept constant and for other livestock the same increase rate as used for EU15 was assumed. Again, as with the yield increase, the diet composition in the future is much debated. E.g., Aiking in Lysen and van Egmond (2008) states that food demand in most studies have been underestimated, emphasizing the role of animal protein in diets, based on the review of food demand projections by the FAO (Bruinsma, 2002), the OECD (OECD/FAO, 2007), IFPRI (Braun *et al*., 2005) and some other studies that estimated biomass potentials for biofuels, including Hoogwijk *et al*. (2005), Perlack *et al*. (2005), Smeets *et al*. (2007) and Wolf *et al.* (2003). An example of an underestimation is the estimated global production of 227 million tons of soybean in 2020 by the IFPRI (Rosegrant *et al*., 2001), which is already produced more than 10 years earlier (2006/7) by a total production volume of 235 million tons. Obviously, a higher food demand would lead to a higher claim on resources. On the other hand, decreasing meat consumption in the future can have a large effect on the necessary inputs for our diet as has been shown in scenario analysis, like in Hoogwijk *et al*. (2005). But unless this scenario of decreasing meat consumption is actually realised, the meat consumption will grow faster than before especially due to the assumed income growth in the developing regions of our world.

Most studies that estimate future dietary demand have based their estimates on current consumption patterns and projected income growth. This implies that poor people that do not have the economic means to purchase the food they need in 2020, are excluded from the demand estimates. According to a study of the MNP (2007), in 2015 a share of 5 to 20% of the population in different regions is still suffering from hunger. In this review the “non-economic” or latent demand has been included to illustrate the extra claim on resources if the poor would consume a (more) healthy diet.

An overview of demand for food can also be found in other publications, e.g. in Lysen and van Egmond (2008), but here we present the OECD-FAO Agricultural Outlook 2008-2017 as benchmark and added a calculated need from the non-economic or latent demand (“extra need” in the legend of Figures 2.5 to 2.8).

The OECD-FAO Outlook provides estimates of the economic demand for two groups of crop commodities in 2005 and those projected for 2017 (Figure 2.5 and 2.6). The demand of 1990 has been added to this figure to illustrate the increase over the past 15 years (1990 – 2005) for comparing with estimated increase in the coming 15 years (2005 – 2020). The extra need has been approached by calculating the contributions of an extra kg of grain and an extra 20 g vegetable oil per day for 850 million people (the estimated number of undernourished people in 2006), in order to raise the average consumption of the world population in 2020 into a more moderate diet (e.g. Luyten, 1994; WRR, 1995).

In 2020 the demand of biofuels expressed as percentage of the non-biofuel demand is 11% for wheat/coarse grains and 19% for vegetable oils (see Figure 2.5 and 2.6, ‘2020a’). All biofuel projections from the OECD-FAO are based on policies in mid-2007 (i.e., before the US EISA or the EU proposal for a biofuel directive) and are therefore underestimations of the total biofuel demand from current policies. The values of the OECD-FAO for global biofuel production approximate to 4% of the transport fuel energy in 2020 and should therefore more than double to realize a 10% blending target. Without biofuels the demand for wheat and coarse grains (mainly food and feed) has grown by 0.7% per year during the period 1990-2005 and is projected to grow by 1.0% for the coming 15 years until 2020. The corresponding figures for the total demand (including biofuels) are 0.9% and 1.6% respectively. The extra need represents an additional increase of 1.3% per annum (see '2020b').

For vegetable oils (only partly used for food and feed) growth rates for non-biofuel demand growth equaled 6.9% (past) and will grow by 2.7% (future) and total demand (including biofuels) has grown by 7.5% (past) and is projected to grow by 4.1% (future). The extra need for vegetable oils only represents 0.4% extra growth per annum during 2005-2020.

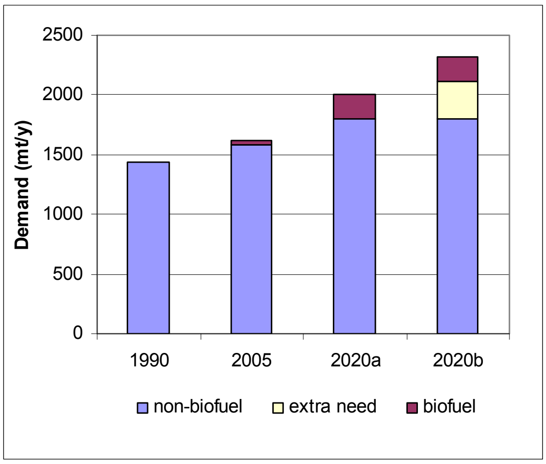


Figure 2.5. Demand for wheat and coarse grains in million tonnes of crop product in 1990, 2005 (from FAOSTAT) and projected for 2020. The projection in 2020 is based on a linear extrapolation of the trend given for 2005 - 2017 in the OECD-FAO Outlook. "Extra need" refers to the non-economic demand (see text).

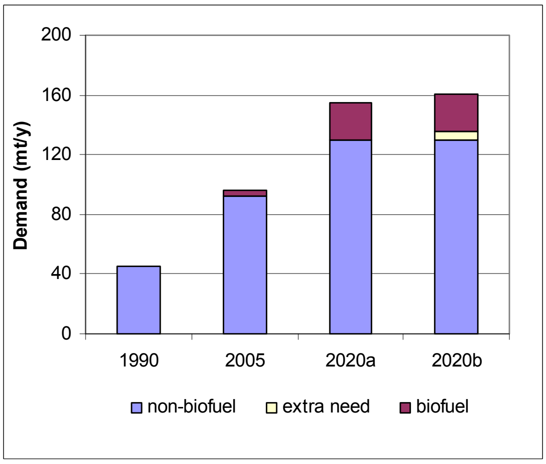


Figure 2.6. Demand for vegetable oils (palm oil, rapeseed oil, soybean oil and sunflower oil) in million tonnes in 1990, 2005 (from FAOSTAT) and projected for 2020. The projection in 2020 is based on a linear extrapolation of the trend given for 2005 - 2017 in the OECD-FAO Outlook. "Extra need" refers to the non-economic demand (see text).

It is clear that in Figure 2.5 the extra need for wheat/coarse grains is significant compared to the demand for (non-)biofuels, whereas for vegetable oils the extra need is relatively small (see Figure 2.6). While it is unrealistic to assume that in 2020 the extra need will have been developed into an economic demand and therefore will actually put a claim on resources, it remains illustrative to depict how much more we should produce for a more adequate diet for the world population.

3.4 Claims on resource use

For evaluating the yield levels that are being assumed in the reviewed studies, a closer look is needed at the biophysical production factors that make up the ultimate yield gains and claims on resources. Most of the studies reviewed did not take the use of natural resources explicitly into consideration or used simplified procedures that do not comply with production ecological concepts, and therefore do not reveal additional claims or limits to production estimates. Globally, the availability of natural resources per person (UN, 2006), primarily water and nutrients, is steadily decreasing and access to resources of especially poor people is rapidly shrinking. We therefore review the availability of and claims on land, water, nutrients and biocides.

Land

With the total demand increase of 1.6% and 4.1% per annum for wheat/coarse grains and vegetable oils respectively according to the OECD-FAO Outlook (see above) and the yield increase estimations of the FAO of 1.2% per annum for both commodities during the coming 30 years (see Table 2.1), more land use for these crops has been projected in 2020 to meet the demand. The OECD-FAO Outlook does not specify the source for this extra land. If less fertile marginal lands are used, then the projected yields can only be realized with a considerable increase in agricultural inputs and therefore investments. On the other hand if (semi)natural lands are used or grassland is converted into arable land, both the greenhouse gas balance and biodiversity are negatively affected because these lands have in general higher carbon stocks in the soil and biodiversity values as compared to arable land. The preferred way to match the high demand is by a further increase in crop yields above the levels projected by the FAO. This is in line with the recent OECD environmental outlook (MNP & OECD, 2008) which states that for limiting the temperature rise to 2 °C we need a global yield increase of 1.6% per year in stead of an average of 1% as predicted for the baseline scenario. The extra yield increase is feasible but not easy as will be explained below (it would require a break with historic trends) and it probably needs more time than the growth in demand dictates in de coming decades due to recent (proposed) policies. It may ultimately mean that the extra demand from biofuels in the short term accelerates expansion of arable land at the global level, if the necessary yield increase is not reached in time. Furthermore, agricultural intensification needed for the extra increase has also been much debated with respect to its local environmental consequences, which calls for a careful case-by-case assessment.

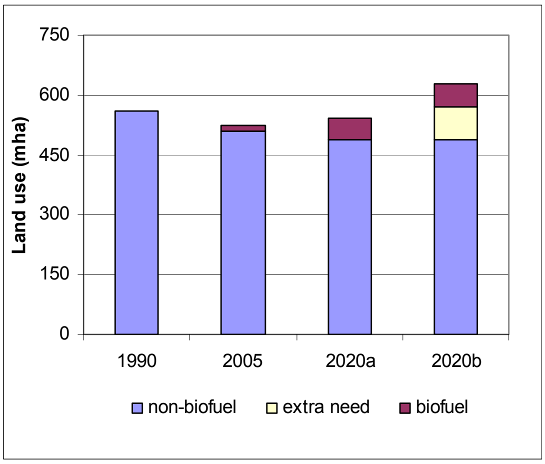


Figure 2.7. Land use for wheat and coarse grains in million ha in 1990, 2005 (from FAOSTAT) and projected for 2020. The projection in 2020 is based on a linear extrapolation of the trend given for 2005 - 2017 in the OECD-FAO Outlook. "Extra need" refers to the non-economic demand (see text).

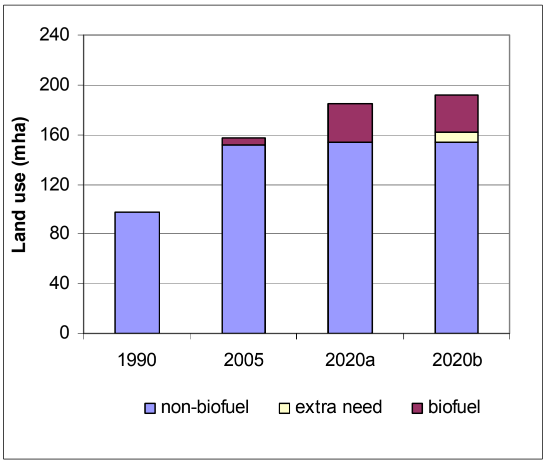


Figure 2.8. Land use for vegetable oils (palm oil, rapeseed oil, soybean oil and sunflower oil) in million ha in 1990, 2005 (from FAOSTAT) and projected for 2020. The projection in 2020 is based on a linear extrapolation of the trend given for 2005 - 2017 in the OECD-FAO Outlook. "Extra need" refers to the non-economic demand (see text).

Both REFUEL and EEA calculate land in the EU to become available for other uses as less land is assumed to be needed in the EU for the production of food and feed for the EU population due to assumed yield increases and/or trade liberalisation with respect to food commodities (expected 'surplus' land according to REFUEL and EEA: 31 and 16 million ha (EU23), respectively in 2020). Because both studies only made calculations for the EU, implications for land use outside the EU have not been addressed explicitly. Also, the studies calculated potential land availability, rather than predicting the actual land use in the future. That will also depend on the degree of trade liberalisation in biofuels as it appears cheaper to produce energy crops in tropical countries as compared to European countries. The baseline scenario in LEITAP estimates 10 million hectares to be released in 2020 against 26 million under trade liberalisation relative to 2000, including current set-aside land, because food consumption is assumed not to increase (much) further in the EU (Nowicki *et al.*, 2006).

Regions differ in their response to higher demands. During the past decades, developments in the EU and N-America showed a declining arable land use, whereas in regions like S-America, Africa and Asia arable land use increased in addition to the increase in crop yields (Figure 2.9). E.g., in S-America total arable land use increased with 20 million ha during the period 1990-2005. Arable land use in the world as a whole increased by some 12% during 1960-2000. According to the OECD-FAO Outlook (Figure 2.7 & 2.8) the use of land for biofuels will cause net expansion of arable land in 2020 relative to 2005, unless yield improvements are realized that are 1.5 to 2.5 times higher than expected, which is not likely to happen (see resource limitations).

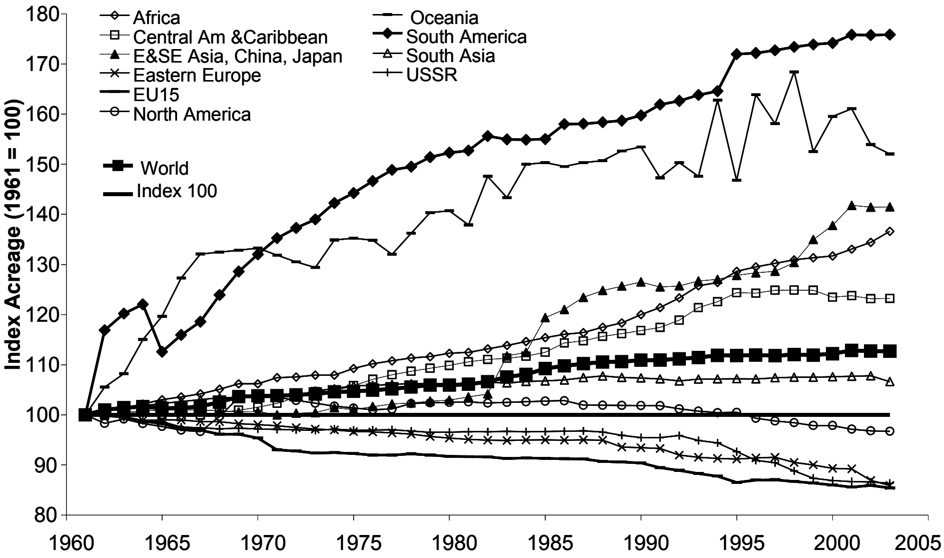


Figure 2.9. Relative changes in arable and permanent crop land use over the past four decades. Source: Based on FAO data.

Projections for future agricultural land use are given in Table 2.3 and an increase in land use for agriculture in the coming decades is predicted by all studies. Projections have been made without considering the obligatory targets of biofuel policies. These policies will increase agricultural land use even further above the baselines of Table 2.3.

Table 2.3. Estimated amounts of global agricultural land use in 2020 due to the increasing demands, according to different assessments (in billion km^2; Kok et al., 2008). The impact of obligatory targets for biofuels have not been included in these figures.

	2000	OECD Environmental Outlook	Agricultural Assessment (IAASTD)	FAO Agriculture Towards 2030
Arable land	15	18	18	17
Pasture land	33	36	37	33
Total agricultural land	49	55	56	51

If land is cheap relative to the other production factors, part of the increased demand will be supplied by an expansion of agricultural lands, as happened in the past in e.g. South-America. Higher prices for crop products in those regions in the future will not only stimulate yield increase but also land expansion if the cost ratio between land and the other factors remain as they have been in the past.

Agricultural production and land use in Africa
Analyses by Conijn and colleagues (in prep) show that the agricultural productivity in sub-Saharan Africa would have to increase by a factor 2-3 on the current agricultural land in order to meet the dietary needs of the 900 million African people, which is close to the production potential under rainfed conditions. As this increase in productivity will take at least 2-3 decades, being optimistic, and the number of people will have increased to some 1.5 billion by then, the productivity increase of 4-5 times would exceed the production potential of the current land, implying the expansion of agricultural land is needed to meet food demand. Therefore, the production of each hectare of biofuels in Africa implies the clearing of new lands, as no lands will become available in the near future. A similar conclusion has also been drawn by MNP (2007) for the whole world.

Water

"The looming water crisis" in the world has generated much concern among scientists and policymakers over the past decades, with 70% of fresh water resources used by agriculture. The availability of water per person has been declining steadily to levels below those required to meet demand (UN, 2006). Lack of water heavily constrains crop production, as it limits carbon fixation through reduced transpiration of plants.

On average, approximating 1000 litres of water is required for 1 kilogram of grains (Steduto *et al.*, 2007), but can exceed 2 to 3 thousand under poor management and even 5 to 10 thousand in rice cultivation. With a vegetarian and meat-rich diet equivalent to 1.5 and 4-5 kg of grains per capita per day (WRR, 1995), it takes a minimum of 1500 litres to over 5000 litres of water per person per day or 547 and 1825 $m^3\ p^{-1}\ y^{-1}$, respectively, which is congruent with estimations of the water requirement for food production of 600-900 $m^3\ p^{-1}\ y^{-1}$ for African and Asian diets and 1700-1800 $m^3\ p^{-1}\ y^{-1}$ for North American diets by Gleick (2000), with a global average of approximately 1250.

There are large differences in local availability of water that should be taken into consideration. E.g., the availability of water per person in India (1750 $m^3\ p^{-1}\ y^{-1}$) and China (2140 $m^3\ p^{-1}\ y^{-1}$; UN, 2006) merely suffices for food production and is declining, while use for other purposes like industry, recreation and domestic use, has still to be accounted for (UN, 2006), often leading to insufficient water for the maintenance of natural ecosystems. There is much scope to enhancing water productivity to cope with the growing water scarcity through a variety of practices including supplemental irrigation, water harvesting, deficit irrigation, precision irrigation techniques and soil-water conservation. Caution is in place however about the scope and ease of achieving these productivity gains. Crop water productivity is already quite high in highly productive regions and gains are therefore limited, while improving water and crop productivity in currently low yielding regions is a cumbersome and time consuming process as it requires implementation of agro-technical and institutional practices to raise productivity of both land and water which is a difficult undertaking (Molden *et al.*, 2007). Attempts to improve water productivity in agriculture face substantial agro-technical challenges and slow implementation rates because of the many socio-cultural and economic modifications required (Senthilkumar *et al.*, 2008). It basically calls for fundamental behavioural change, like the replacement of women labour by male labour because of the introduced equipment and the acceptance of increased risk in production. Climate change is expected to exacerbate the adverse conditions in regions that are in the greatest need for productivity increase, further increasing yield variability that is common in low productive regions.

The additional claim on water for the production of biomass for biofuels will therefore put a claim on additional water resources that either would have to be withdrawn from current sweet water sources that are limited or from expansion of agricultural land to capture more rainwater.

Nutrients

While the surface of the land is needed for capturing solar radiation, the quality of the soil is another critical factor for crop productivity. Before the widespread use of artificial fertilizers when only a moderate level of organic material was recycled as nutrient source in biophysically favorable areas, maximum yield levels reached 2 – 2.5 tonnes of grain equivalents per hectare (WRR, 1995; Bindraban *et al.*, 2006). Increase in crop yields will need the input of artificial fertilizers and/or higher amounts of organic fertilizers and without these (extra) inputs higher yield levels cannot be maintained sustainably. On soils with low fertility therefore only low yields can be obtained without the input of fertilizer. These situations are fairly common especially when costs for fertilizers cannot be recovered or when production risks are too high because of highly variable production conditions, primarily rainfall or pest and disease pressure. The soils of the entire sub-Saharan continent, for instance, have already been depleted to a large extent (Smaling *et al.*, 1993).

Soil organic matter is a major determinant of soil quality. It prevents soil erosion, enhances water infiltration and water holding capacity, provides a binding agent for nutrients and therefore prevents nutrients from leaching and acts as a reserve pool of nutrients for plant uptake (Bell and van Keulen, 1995). Loss of soil organic matter occurs when the input of fresh organic material declines, e.g. by removal of crop by-products, and also after clearing of natural lands or grassland for conversion into arable land (e.g. Titonell *et al.*, 2007; Zingore *et al.*, 2005). Increasing soil fertility under less favorable conditions generally is a long term process where the combined application of external nutrients through organic matter and artificial fertilizer gives the most promising results to increase crop yield (e.g. Breman *et al.*, 2001). Dry or wet deposition of nutrients and nitrogen fixation by legumes also introduce nutrients to the soil, but these quantities are not sufficient to sustain a high productivity. Nitrogen fixation rates will be low also under adverse environmental conditions as the legumes also suffer growth limitation. These complex eco-physiological interactions and the economic and institutional aspect of facilitating fertilizer use are not adequately analyzed in the reviewed studies. Some studies have incorporated the price of fertilizer, but it is unknown whether the fertilizer price development and associated application of fertilizers match the projected higher yields in the future that will generally need more fertilizers.

A special case of limitation to crop production in the future is likely to arise from the declining availability of phosphor. Phosphor is a non-renewable resource which is mainly produced from phosphate rock that can only be found in a few mines in the world. At the end of the cycle phosphor is either temporarily stored in the soil or ends up in the oceans. Given the current known sources it has been estimated that supply can meet the demand for the coming 50 – 100 years (source: http://phosphorusfutures.net; Martens, 2008; Duley 2001), depending on rates of use and amount that can be extracted from the mines, without considering yet the production of biofuels. For the short term (until 2020) it seems that there is no severe limitation with respect to the availability of phosphorus, but for the medium term it is of utmost importance to recycle phosphor to the maximum possible, which also includes the phosphorus in the biomass used for bio-energy.

In ecological processes, part of the nutrients is lost to the environment after application to agricultural fields. Especially nitrogen plays a key role because it is highly mobile in the soil and leaches to the groundwater as nitrate causing eutrophication and consequent loss of biodiversity (Admiraal *et al.*, 1989). It can also be emitted to the atmosphere, partly as the greenhouse gas N_2O. Intensification and expansion of arable production as has been projected in all studies lead to higher losses of nutrients with the presently used technology and management. E.g. using the set-aside land (10% in the EU) for annual energy crops and the associated application of nitrogen and phosphorus will lead to higher losses of these nutrients. Increasingly, environmental legislation in the EU and USA puts limits to the use of nutrients in crop production (including grassland farming) because of environmental concerns and may therefore also affect the yield increase in those regions in the future. Most studies have not explicitly combined policies that aim at reducing nutrient loads from agriculture with the extra fertilizer needs of projected higher biomass production in the future.

Biocides

Crop production is threatened by pest and disease infestations and because of competition with weeds. Complete crop failure may result from these biotic stresses that can be controlled mechanically or chemically. Mechanical control, such as weeding, incur use of equipment, labor and energy. Biocides, in addition to these inputs, are produced industrially, and have in the past been detrimental to ecosystems and environment. Over time their toxicity to non-target species and to the environment has decreased, application rates have come down because of integrated approaches such as Integrated Pest Management, and organic agents and biological control methods are increasingly being used.

Biocides therefore have been and still are a potential health risk both for humans as for other life forms on earth. The use of biocides to continue to secure yield levels might increase with an ever larger fraction of the world's surface being used for agro-production systems. Jatropha curcas plantations for the production of biofuels may, for instance, suffer from rust epidemics and spraying with a biocide seems the only remedy at the moment (refs?). On the one hand, the use of biocides for biofuel crops is likely to be rather small relative to the use of existing practices of biocide-intensive crops, like cotton, banana, potato, etc., but the cultivation of new species with little knowledge might, on the other hand, create new and unknown pest and disease epidemics that are difficult to control.

The control of pest and diseases and weeds is an ongoing effort that needs continuous breeding effort, as resistance and tolerance of varieties are broken over time. These are lengthy processes that may taken several years to decades. Biotechnological approaches can accelerate these processes, and facilitate the search for reducing biocide application, but resistance can still be broken, and even higher amounts of biocides might be required over time. Findings on these effects are still under investigation, but a wide range of options and developments will remain necessary in the complex biological systems, due to strong interactions between weather conditions, application methods, climate, soil conditions, the prevalence of other biotic stress factors, etc.

Overall, an increased use of biocides can be expected with the expansion of production areas for agricultural commodities, including food, feed and fuel. None of the studies have discussed this aspect of growing energy crops for bio-energy.

3.5 Biomass residues

In this paragraph, two examples of biomass residues that are used as inputs for agricultural fields are given and discussed with respect to their possible impacts on agricultural productivity.

Compost is made from organic residues, like kitchen and garden residues from households, and is used in the Netherlands to improve soil conditions. During the process of composting, the organic matter is partly decomposed and CO_2 is released, and the compost contains the more resistant organic carbon. Recently, the demand for bio-energy has stimulated new developments by placing an industrial fermentation process before the 'original' composting process. Biogas production is first captured and the more resistant carbon is left behind as input for the further processing into compost. Because the compost yield in both situations is more or less equal, this new process is making better use of the biomass residue and competition between functions is avoided. Similarly, animal manure is collected in fermentation tanks for production of biogas and electricity, which does not endanger the remaining use as fertilizer for the field. It should be noted however, that also easily degradable biomass, such as maize for instance, is added to increase the biogas production, in the Netherlands up to a maximum allowed 50% of the total digestible dry matter.

In many studies, a large portion of biomass residue is considered to be found on agricultural lands, i.e. the non-harvested part of a crop, like straw or leaves. Straw that will be harvested as fuel for a power plant instead of being incorporated into the soil, will lead to a decline in soil carbon, nitrogen and sulphur stocks, whereas the amounts of other nutrients in the soil, like phosphorous, can be sustained if effective recycling is realized. Depending on local conditions (soil organic matter level, drought events, erosion susceptibility, etc), the decline in soil carbon can have a reducing effect on future crop yields and the loss of nitrogen and sulphur may have to be compensated by increased external inputs. In any case the decline of C and possible increase of external inputs should be taken into account when calculating the greenhouse gas balance. Total loss of soil carbon due to straw removal might be as high as 20 -30 times the annual net reduction of greenhouse gas from the bio-energy derived from the straw. In case of (partial) fermentation of the feedstock, the more resistant part of the straw including the nutrients should be recycled to maintain soil fertility as much as possible. Without return flow, soil organic matter may decrease up to 50% of the initial level prior to removing straw from the field, which depends on interacting processes within the cropping system, the share of straw crop in the rotation, management, use of organic fertilizer, weather conditions, soil type, hydrology and fertilizer use. Removal of straw also affects soil biota directly because of reduced organic matter availability for their intake, causing changes in the total active biomass of these biota. The extent to which this happens and the ultimate impact on soil quality is considered important, but is still not quantified adequately. Ultimately land quality can be negatively affected, causing biomass production to decline over time, a process which is highly location specific. The proportion of straw that can be allocated for bio-energy should therefore be estimated locally, to prevent soil degradation and no general statements can be made, neither can the availability of straw be considered as an unlimited or invariable input for biofuels. If the development of 2nd generation biofuel technology results in an increased demand for straw, these considerations should carefully be taken into account.

3.6 Agricultural developments

Agriculture and agricultural development have been strongly stimulated after the Second World War in both developed and currently emerging economies, but has been neglected over the past two decades world wide. The recent food scarcity and a renewed recognition that agriculture serves as the starting engine of overall economic development (UN Millennium Project 2005; World Bank, 2007) might slowly turn the tide as agriculture has moved up on the political agenda. It has lead to the release of a large number of reports by scientific, governmental and multilateral institutions (e.g. InterAcademy Council 2004; IAASTD, 2008).

It is generally realized that there is no single silver bullet to increase the productivity in agriculture, as it concerns a complex developmental process. Agro-ecological approaches are needed to optimize productivity in various regions under different conditions. Market-driven development is considered the key to contribute to fighting hunger and to make agriculture a driver for development, but brings with it both significant opportunities and considerable risks for the rural poor. Social and political institutions may promote or inhibit the potential contribution of agriculture to economic development and therefore a conducive institutional environment is critical and includes enabling policies at the national and global levels and functioning partnerships between public, private and civil society actors.

Because of the under-investments over the past decades, in many regions in the world, it will take many years if not decades to put all these conditions in place. The opportunities to increase yield are hampered because of the considerable slow down of public investments in crop research and extension and infrastructural investments such as in irrigation. Also, agriculture is already facing the challenge to overcome its degrading and ever more competitive resource base. Whereas increased financial investment would stimulate the rate of yield increase to go up, the ecological limits are becoming increasingly important that cannot be simply overcome, likely leading to an overall decline in the rate of yield increase in future. Moreover, the time lag in the development and implementation of agro-technology may have caused the disinvestments to go unnoticed. Crop breeding is a process that takes 8 to over 15 years for annual crops and the released varieties may last for a decade or so. Hence, no decline in productivity will be experienced after a disinvestment for more than a decade. It will, vice versa take many years for agro-innovations like breeding to boost agricultural productivity again. Most fertile and suitable lands have already been converted into agricultural areas and increasing the productivity on remaining less productive lands will be a more cumbersome and time consuming exercise. While increased investment will speed up developments, some agro-ecological and institutional processes cannot easily be accelerated.

Installation of favourable institutional conditions such as support to research and extension, and new agricultural industry for producing mechanical equipment and agro-chemicals, along with stable market conditions including subsidies, guaranteed prices and purchasing, provided the conditions in the past for the technological innovations that boosted agricultural productivity. Creating these conditions in less favourable or marginal biophysical environments has appeared difficult resulting in limited productivity gains only (Bindraban *et al*., 2008). Studies that estimate production potentials of biofuels generally alleviate current agricultural land for the production of biofuels. However globally, this is unlikely to be true for the coming 10 to even 20 years, as the increasing demand for food and biofuel is likely to exceed the productivity increase in agriculture. In addition, current economic analyses consider economic demand only, which underestimates the need for productivity increase to meet dietary needs of poor and hungry people. Even with drastic innovations that would break past trends and accelerate productivity increase, it will be difficult to meet all demands, without expansion of the production area.

4 Conversion technologies of biofuels

4.1 Distinction between first and second generation biofuels

In this chapter, the existing conversion technologies and those being developed for the production of biofuels are discussed. This report distinguishes first and second generation biofuels. It is important to make a distinction between first and second generation feedstock for biofuels, as the presumed socio-economic and environmental impacts are considered to be different.

The difference between these two types of biofuels is not always clearly defined. Here, a distinction is made based on feedstock used and we consider the first generation biofuels as originating from oil, sugar or starch crops. Second generation biofuels originate from lignocellulosic crops or residues. Table 3.2 summarises the biofuels and their feedstock as being first or second generation (REFUEL, 2008). This classification is used in this report. Information on the production processes is provided in Section 3.5.

Table 3.1. The biofuels and their feedstock according to the classification as being first or second generation. Source: REFUEL, 2008.

Feedstock			Classification	Biofuels				
				Bio-Diesel	Bio-Ethanol	FT-Diesel	Bio-DME	Bio-SNG
Energy crops	Lignocellulosic crops	Woody plants (SRF)	2nd		x	x	x	x
		Herbaceous plants	2nd		x	x	x	x
	Oil crops	Rapeseed	1st	x				
		Sunflower	1st	x				
		Palm oil	1st	x				
	Sugar crops	Sugar Beet	1st		x			
		Sugar Cane	1st		x			
	Starch crops	Wheat	1st		x			
		Maize	1st		x			
		Triticale	1st		x			
		Sweet sorghum	1st		x			
Residues	From agriculture	Digestible	1st		x			x
		Non-digestible (straw)	2nd		x	x	x	x
	Form forestry		2nd		x	x	x	x
	From woody industry		2nd		x	x	x	x
Waste	Organic waste	Used oils/fats/fatty acids	1st	x				

4.2 Current consumption and production of biofuels

The current (2007) consumption of biofuels in Europe in terms of energy content is 2.6% of the total fuel consumption for road transport. The lion share of these biofuels in Europe is biodiesel (75%), followed by bioethanol (15%) and vegetable oil (10%) (EurObserv'ER, 2008).

Biodiesel production

Figure 3.1.shows that biodiesel production increased rapidly in the EU over the past years. Currently, there are 241 biodiesel plants installed, with a production capacity of 16 Mtonnes as

of July 2008. The actual production in 2007 reached nearly 6 Mtonnes (EBB, 2008), or about 7 billion litres[1]. This is almost 3.7% of the current diesel consumption of about 190 billion litres.

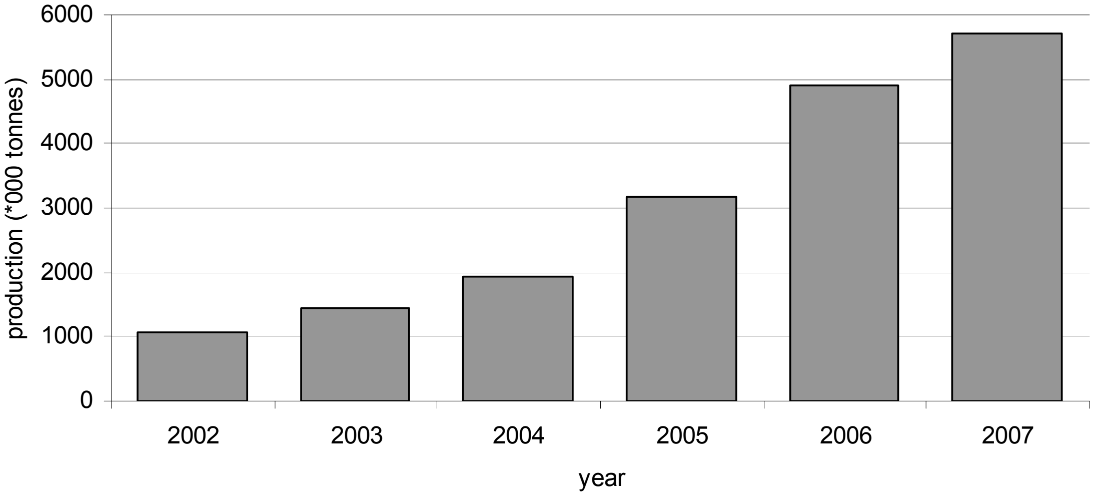


Figure 3.1. Biodiesel production in Europe in the past years. Source: EBB, 2008.

Most of the biodiesel produced in 2006 in the EU originates from rapeseed (84%), and sunflower (13%) (EUBIA, 2008). In Europe, the share of biodiesel from soybean, palm oil or other oils is only 1% each (EUBIA, 2008).

Globally, the production of biodiesel from oil crops and waste in 2007 is estimated at 8 billion litres (REN21, 2007), or about 6.8 Mtonnes. Also in this case, a rapid growth has been realised of 50% compared to 2005. By far the largest amount of biodiesel is produced in Europe with Germany taking a leading position with 2.80 billion litres.

Bioethanol production

In 2007, the European bioethanol production was 1.7 billion litres, which corresponds with 1% of the total gasoline consumption in Europe of about 170 billion litres. The production capacity was 4.3 billion litres and another 3.7 billion is under construction (Ebio, 2008). The global production of bioethanol in 2007 from sugar and starch crops is estimated at 46 billion litres (REN21, 2008). This is an 18% increase compared to 2005. Most bio-ethanol is produced in the US (18.3 billion) and Brazil (17.5 billion). In Europe, the largest production capacity is in France (30%), followed by Germany (23%) and Spain (13%) (Ebio, 2008). In Europe, most of the ethanol is produced from cereals, wheat, maize or from sugar juice, see Figure 3.2.

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[1] Assuming 0.85 kg/l

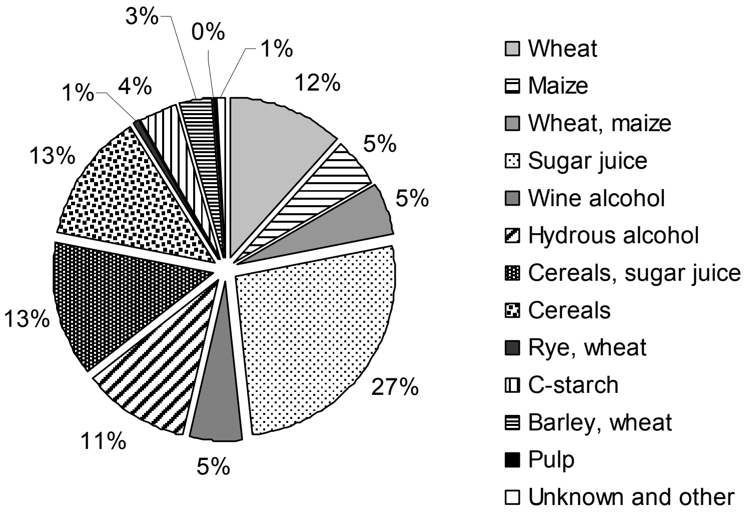

Figure 3.2. The feedstock used for bioethanol production in Europe. Source: EBIO, 2008.

4.3 Chain analyses comparing different biofuel routes

The evaluation of biofuel routes involves the entire production chain, including the production and transport of the feedstock, the conversion and the transport of the fuel. The efficiency of the technological performance is evaluated on the basis of the performance with regard to:
- GHG emissions
- land efficiency
- production costs

Various studies compare life cycle analyses of biofuel routes e.g. the Well to Wheel study (Edwards et al., 2006), E4Tech (2008), Hamelinck and Hoogwijk (2007), Kok et al., (2008) and REFUEL (2008). Important for these chain analyses are:
- the type of conversion routes and feedstocks included,
- the allocation principle used for by-products,
- the main data assumptions,
- the system boundaries.

Several allocation principles are applied to allocate the energy consumption and GHG emissions to various by-products.
- Physical allocation based on the energy content of by-products
- Economic allocation based on the economic value of by-products
- Allocation based on substitution principles.

The physical allocation method based on the energy content of products and by-products will be used for evaluating the GHG emissions of biofuel routes under the EC directive. This method that allocates emissions to by-product based on the energy content of the (by-)products is easily applicable (compared to the substitution method) and least subject to changes over time (compared to the economic allocation method). Eickhout *et al*. (2008) have compared the results in terms of GHG savings per biofuel route i.e. no allocation applied, physical allocation and the substitution method. Hamelinck and Hoogwijk (2007) applied the economic allocation method, E4Tech (2008) applied the physical allocation method while REFUEL (2008) based the ”Well to wheel” study on substitution principles. These results are summarised in Figure 3.3.

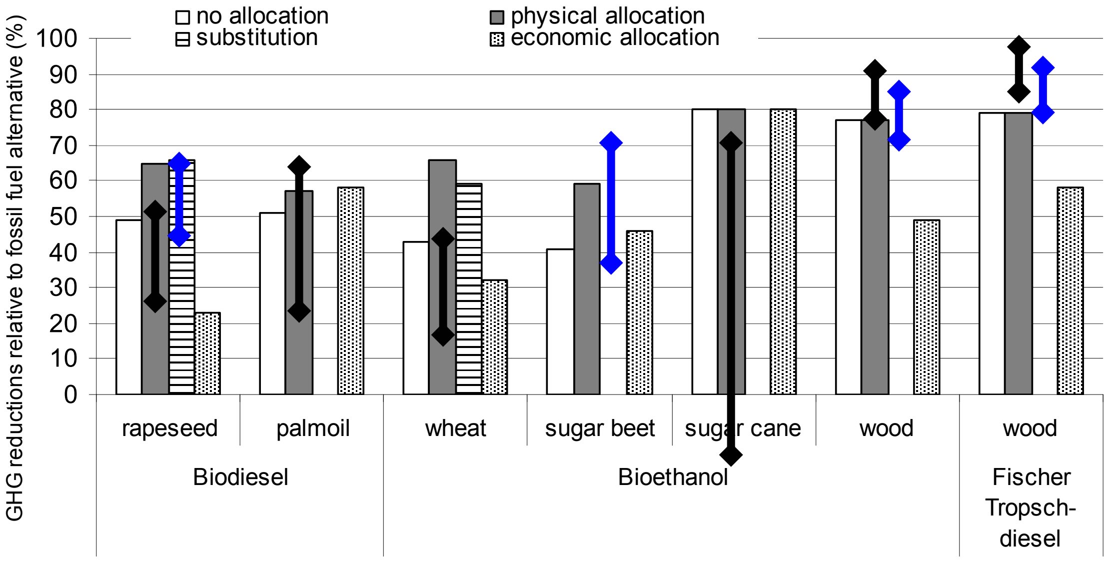

Figure 3.3. Avoided GHG emissions per conversion route for different allocation methods and different sources. No allocation, substitution and physical allocation are based on Eickhout et al., 2008. Economic allocation is taken from Hamelinck and Hoogwijk, 2007. In addition, two other studies are included. The black and blue lines indicate the ranges provided by E4Tech, 2008 and REFUEL, 2008 based on physical and substitution allocation method. (Data read from graphs).

Figure 3.3 reveals a wide range of avoided GHG emission estimates for different biofuel routes depending on the calculation method applied, even within a similar allocation method. For economic allocation and substitution, the main assumptions on prices or substitution routes are important. The main reason for the variation in the physical allocation method is:

- the assumed fuel used in the chain for first generation, i.e. whether fossil fuels or biofuels will be used during production, processing and transport,
- the main assumptions on the food production practice.

In particular the production management of the energy crops can cause significant ranges. At high levels of nutrient inputs, the reductions can be offset by N_2O emissions (Smeets, 2008; Crutzen et al., 2007).

The difference in reduced GHG emissions due the use of fossil fuel of biomass in the production chain appears also important as can be derived from Figure 3.4. Second generation routes mostly use residual biomass, while additional biomass is required for first generation routes. Higher levels of avoided emissions can be achieved using biomass, in the production chain. However, it is questionable whether this is a (cost) efficient approach.

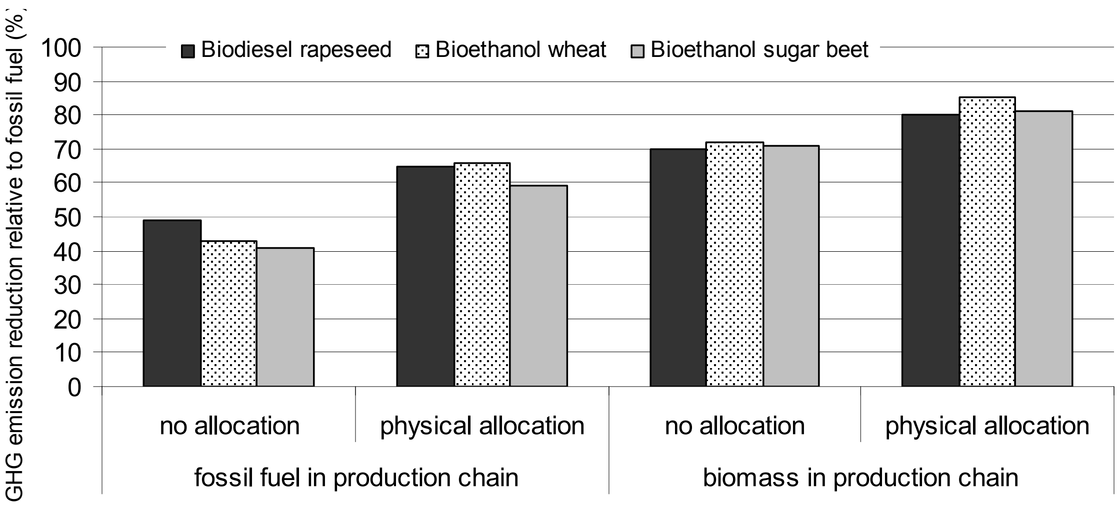

Figure 3.4. Avoided GHG emission compared to reference situation when fossil fuel or biomass is used in the production chain for three different feedstock. Source: Eickhout et al., 2008.

When comparing the avoided GHG emissions per land area, the allocation method appears important also (Figure 3.5). The allocation is also applied to the hectare. In the physical and economic allocation method for instance, , only part of the area used for the crop is allocated to the biofuel. The substitution method can lead to further extreme results. Eickhout and colleagues (2008) for instance assume that the land requirement for soy reduces because of the substitution of soy-meal by Distiller's Dried Grain Soluble (DDGS), the by-product of the ethanol production from wheat. There could even be a gain in land area because of the lower productivity of soy compared to wheat. However, the question whether this substitution is realistic primarily because of great differences in fodder quality between soybean meal and DDGS, has not been evaluated in the study. Because of the strong sensitivity of the allocation methods to assumptions, the physical allocation method is preferred for evaluation and comparison, as this type of substitution might occur in reality.

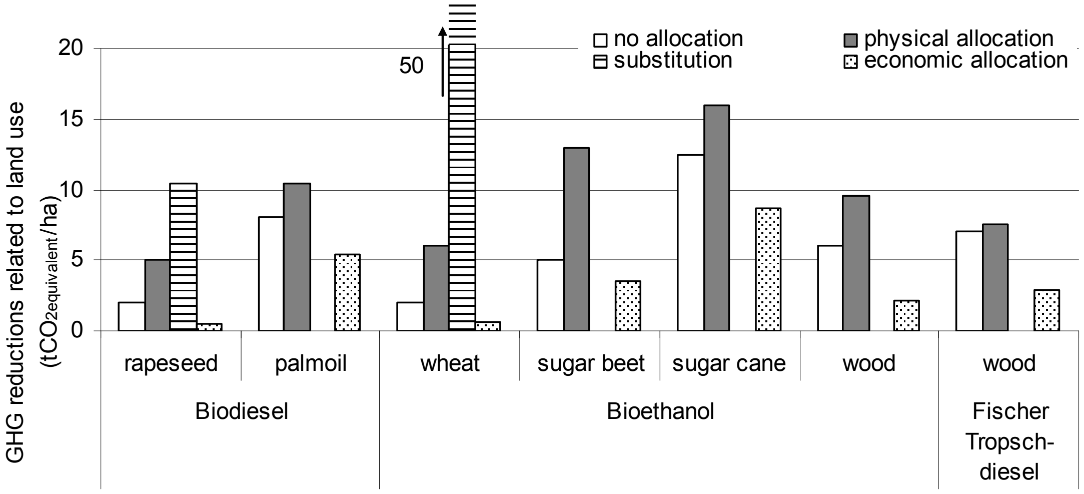

Figure 3.5. GHG reduction for different biofuel routes relative to land use allocated to the biofuel. Source: Eickhout et al., 2008.

In addition to allocation mechanisms, much variation is found in the amount of prevented GHG emissions, primarily due to large differences in cultivation practices in the field. Much of the gains can be lost with poor agronomic practices, such as unbalanced use of fertilizers.

Cost

Similar to the GHG performance, the costs should also be evaluated and compared in terms of the entire production chain. Most of the studies mentioned above did not include a similar cost analyses on different allocation methods. Hamelinck and Hoogwijk (2007) provide cost data based on economic allocation (Figure 3.6). These figures are subject to assumptions on market values for by-products. The Sugar cane to ethanol conversion produces energy as by-product. Therefore, at higher oil prices, here set at 50 US$/barrel, the gains of the by-products are higher. Uyterlinde and colleagues (2008) have also presented data for costs for average food-based and non-food based ethanol production, and for food-based biodiesel production. These values are much higher than those from Hamelinck and Hoogwijk, presumably because of differences in assumptions on market values of by-products.

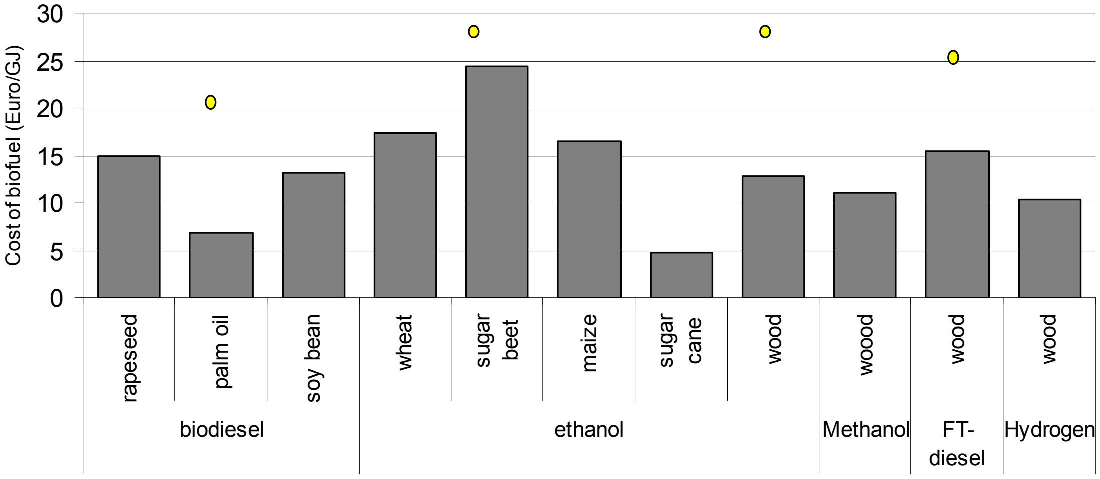

Figure 3.6. Bars represent cost of biofuel routes at Euro/GJ[2] *product based on economic allocation method at an oil price of 50 US$/barrel. Source: Hamelink and Hoogwijk, 2007 (bars); Uyterlinde et al.,2008 (dots).*

Comparing first and second generation biofuel chains

Comparison of the first and second generation biofuel routes reveals that:

- There seems to be a slightly higher prevented GHG emission for wood based routes per unit product.
- The estimates are complicated because of the by-products in the first generation routes and values vary significantly depending on the allocation method applied and the underlying assumptions.
- The assumptions on the feedstock production and costs strongly affect the estimated values.
- First generation routes might outperform second generation routes when the by-products could be used as feed.

There are other reasons however in favour of second generation routes over first generation routes (see also Ros, 2008):

- A wider range of feedstock can be used as most second generation routes can include agricultural and forestry residues, wood or even waste. This reduces the risks in the supply chain and improves their performance in terms of production costs, GHG balance and production per land area.
- There are more technological developments expected on the long term for second generation biofuels, while fewer gains in efficiency are possible in first generation routes.
- Wood production might require less fertilizers, which would reduce nitrogen emission.
- The use of gasification technologies and ethanol production may allow the use of Carbon Capture and Storage in combination with biofuel production, resulting in net negative emissions.

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[2] Approximated 0.021 GJ/Litre for bio-ethanol and 0.034 GJ/Litre for biodiesel

- The use of gasification technologies may stimulate developments in bio refineries leading to higher quality biomass products.

4.4 The future market for biofuels

The current total gasoline consumption in the EU is about 170 billion litres a year as compared to 190 billion litres for diesel (WRI, 2008). According to PRIMES scenarios (2003), the main growth is expected in the diesel consumption. DG AGRI analyses the impact of 10% obligatory blending of biofuel (DG AGRI, 2007) using a comparable share of 55% of transport fuels from diesel in 2020. Using the growth rates from PRIMES (2003), a total market of about 170 billion litters of gasoline and about 240 billion litres of diesel is expected in the EU in 2020.

In energy terms, the total transport sector consumed 365 Mtoe (15.3 EJ) in 2005, of which 302 Mtoe (12.7 EJ) for road transport, which is estimated to increase to 350 Mtoe (14.7 EJ) in 2020. Therefore, the target of 10% biofuels in 2020 set by the European Commission (DG AGRI, 2007), would require the use of 34.6 Mtoe (1.5 EJ) of biofuels.

Several studies have estimated the future market of agricultural commodities, including biofuels, e.g. DG AGRI (2007) and Eururalis (Klijn et al., 2008), but show that making estimations is difficult because results are sensitive to many (unknown) input parameters. Still however it is relevant to illustrate the estimate for which we use the DG AGRI study (2007).

DG AGRI has estimated scenarios of possible developments in the future market of biofuels in the EU. Based on current biofuels policies, import and production rates and price developments they have assessed the cereals, oilseed and vegetable oil market in 2020. They have used following assumptions:

- Despite unknowns, the assumed share of second generation biofuel is set at 30% of domestic needs in 2020.
- 55% of future consumption of transport fuels in 2020 would be diesel.
- An open import market for biodiesel, oilseeds and vegetable oils is assumed. The ethanol market is protected. For second generation feedstock an import share of 20% has been assumed, mainly wood chips from temperate climate zones.
- The analysis assumes that production of biodiesel would remain in the EU considering its present international competitiveness.
- The analyses assumes a fossil fuel price of 48 Euro per barrel[3].

The market analyses show that feedstock imports would serve about 20% of the biofuels production. About half of them would be first generation feedstock mainly oil seeds and vegetable oils. Sensitivity analyses show that the assumed share of second generation feedstock is important for these results as well as different import restrictions. Eururalis (Klijn et al., 2008) for instance showed that import also depends on liberalisation of the market.

4.5 Future market of first and second generation biofuels

The current production of biodiesel and bio-ethanol is all classified as first generation. The second generation alternative for biodiesel would come from Fischer-Tropsch diesel (FT-diesel) and for bio-ethanol from ethanol produced from lingo-cellulosic feedstock. Other alternatives are the production of methanol or hydrogen from lignocellulosic feedstock, but have not been further considered here.

Ethanol

The second generation plants currently under development are mainly ethanol plants from lignocellulosic feedstock. Globally there is a rapidly increasing interest in cellulosic ethanol.

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[3] Taking the exchange rate of 1 July 2007, this equals 65 US$/barrel

There are many initiatives and there is significant funding by DOE[4] in the USA. A few pilot plants are operating and commercialization is expected in the coming 2 – 4 years (Hamelinck and Koop, 2008). Most of the plants use a mix of residues e.g. waste wood, straw or bagasse.

Based on different magazines and press releases, an estimate is made by Hamelinck and Koop (2008) of the second generation ethanol plants globally in the pipeline of almost 1.5 billion litres per year litres in 2012 (Figure 3.7). These plants are mainly planned in the US. In 2006, the global production of bioethanol from sugar and starch crops is estimated at 39 billion litres (REN21, 2008). This implies that in 2010 the global share of second generation ethanol will be small but not negligible, taking the current plans as a basis.

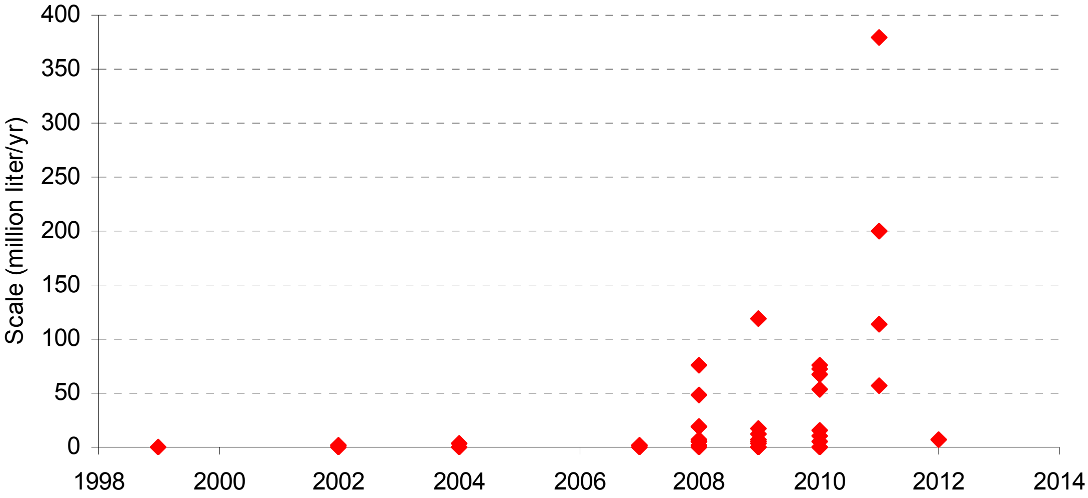

Figure 3.7. The scale and starting date of different second generation ethanol plants established and in planning up to 2012, primarily installed in the USA (Hamelinck and Koop, 2008).

FT-diesel

Most important initiatives in FT-diesel seem to originate in Europe. Earlier this year, the German company Choren opened its BTL demo in Freiberg, announcing it will go for a 200 MW ‘sigma’ plant to be realized by 2012. Recently, Choren and Norske Skog announced an initiative for a BTL plant on the basis of black liquor, a side-product in the latter’s paper production process. Other initiatives, however, seem to be rare, possibly because of the technology and investment risks. FT-diesel plants do not have the advantages as in bio-ethanol production in terms of feedstock, interlinked technologies and gradual investments, but require large scale initial investments, see also Chapter 4.

Share of first and second generation biofuels in 2020

As is also indicated above, the impact of first and second generation biofuels are different. It is therefore important when analysing the impact of the 10% biofuel share in 2020, to assume the share of first and second generation biofuels.

The market for biofuels is considered not to be mature enough to extrapolate current growth trends. Future market shares need to be estimated in combination with policy assumptions and price developments of oil and feedstock. Most studies assume that the second generation biofuels will enter the market after 2010 or will even not available before 2020 (EEA (2006); REFUEL (2007); IMPACT (Rosegrant, 2008). In the REFUEL modelling exercise, the technical starting point used is 2010 but the second generation biofuels do not enter the market until 2013-2015 depending on input assumptions. The main parameter influencing future share of second generation biofuels are the policy conditions to stimulate second generation technologies.

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[4] Department of Energy

The REFUEL project has analysed the policy and strategies required for deployment of second generation biofuels. It was recognised that various stakeholders are involved and policies in different policy domains might be applied to enhance second generation biofuel development.

5 Capital availability and investments

As with many new energy technologies, the introduction of biofuels will require substantial amounts of new investments, particularly for research and development of conversion technologies and the realization of conversion installations (see Chapter 3). Investments can be a limiting factor for biofuels introduction in two ways:

- A specific technology may require high overall amounts of investments for R&D and infrastructure, particularly in a situation of obligatory blending targets that requires a rapid introduction rate of the technology to substantial volumes. In this case, the central question is whether realizing these overall amounts of investments is feasible for the economy as a whole.
- Per project, required investments will come with a specific investment risk. New technologies may fail or be less successful than expected, and market circumstance may deviate from original expectations. In this case, the central question is how risks affect the required risk premium, and to what extent these risks could be reduced.

In most of the studies reviewed for this project, investments and the problems that may be expected for their mobilization were not addressed quantitatively. Therefore, we make use of several additional literature sources for an assessment of investment potentials and possible bottlenecks for the further penetration of biofuels.

5.1 Investments and entailed risks per project

In this context, there is a clear difference between currently used 1st generation biofuels and perceived 2nd generation biofuels.

- Per project, investment costs for conventional biodiesel and ethanol installations are typically in the order of several tens of million Euros (Deurwaarder *et al*., 2007). Even for the largest installations foreseen, investments are not expected to exceed € 50 Million. For 2nd generation installations, investment costs per unit product are substantially higher. Furthermore, the reference size of the installation will probably become larger than that of conventional installations. Particularly for biofuels production via gasification-based routes, such as FT-diesel, investment costs will be in the order of several hundreds of million Euros per project (Deurwaarder *et al*., 2007).
- Additionally, the share of investment costs in the total production costs of biofuels differs between 1st and 2nd generation biofuels. As Figure 4.1 illustrates, capital costs consist of a relatively minor share in production costs for 1st generation biofuels, while it makes up more than 50% of production costs for 2nd generation biofuels[5]. This also leads to different risk profile for these respective investments:
    - 1st generation installations make use of conventional, proven technologies. Investments in 1st generation biofuels are susceptible to changes in commodity prices, both of their feedstock and of the biofuels produced. On the other hand, as most of the costs are variable, an installation can respond to poor market circumstances by reducing its production, or even temporary shutdown, without too high remaining capital costs. This is indeed observed in practice with current high prices for agricultural commodities and has been practice for bio-ethanol production in the past in Brazil.
    - 2nd generation installations make use of innovative and yet to be developed technologies that have not yet fully proven their applicability. Investments in 2nd generation biofuels are less sensitive to changes in commodity prices, more susceptible to uncertain investment costs, and more susceptible to changes in biofuel prices compared to 1st generation routes. The latter is due to their high capital costs: these

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[5]: After introduction of the technology, learning-by-doing will lead to lower investment costs. However, a substantial structural difference between investment costs shares between 1st and 2nd generation biofuel technologies will remain.

installations need to continue their operation, also in periods where the market for biofuels is poor.

In short, investment risks in 2nd generation technologies can be considered substantially higher due to the innovativeness of the technology and the higher susceptibility to booms and busts in biofuels markets. Usually, investors will try to hedge against the most essential risks, e.g. by trading derivative, but such constructions do not seem to be readily available yet for this specific market. Generally, a higher risk will lead to a higher risk premium to be rewarded, which can be translated into a higher project interest rate. The only reviewed study that specifies investments, REFUEL does not differentiate the applied project interest rate between different technologies (Deurwaarder, 2007).

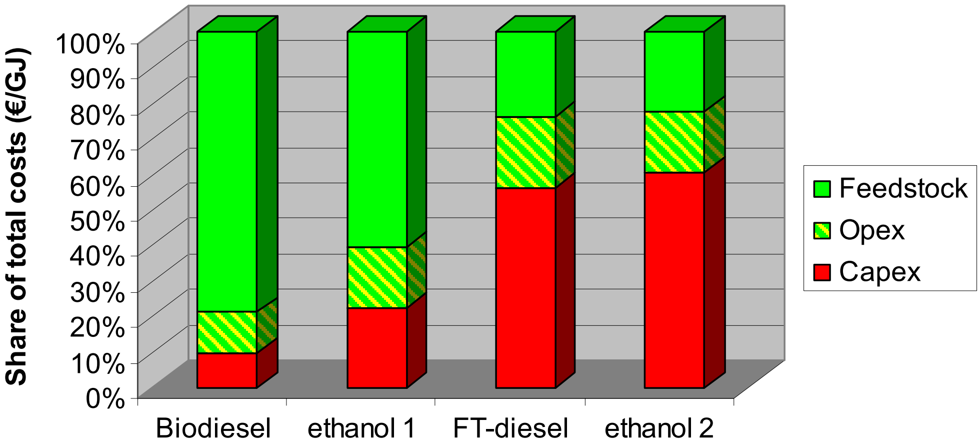

Figure 4.1. Relative shares of feedstock costs, operational expenditures (Opex) and capital expenditures (Capex) in total biofuel cost price for different biofuels. Source: Londo et al., (2008).

5.2 Overall investment efforts for biofuels

In order to introduce biofuels on a significant scale, total required investments may also be a point of attention. Again, the difference between 1st and 2nd generation technologies is significant.

In Table 4.1, an indicative calculation is shown of required investment costs per GJ energy produced and per ton CO_2 avoided, for 1st and 2nd generation technologies as well as for an average mix of new technologies as applied in one of the scenarios of the IEA Energy Technology Perspectives (IEA, 2008). Investments include both R&D investments and funding by governments and industries, and industry investments in commercial installations, the latter taking the lion's share. Both in terms of investments per energy production and per tonne avoided CO_2, 2nd generation biofuels appear to be highly capital-intensive. On the other hand, 1st generation investment costs are relatively low, particularly when related to their energy production capacity.

Table 4.1. Indication of specific investment costs for 1st and 2nd generation biofuels, and for a mix of renewable and other GHG and fossil energy mitigating technologies.

	Investment costs per unit energy produced (\$/GJ.yr)	Investment costs per unit GHG mitigation (\$/t CO_2.yr)
Average all technologies[1]	50	700
1st generation biofuels[2]	20	700
2nd generation biofuels[1]	170	2800

[1] *Source: IEA Energy Technology Perspectives (2008), ACT Map scenario, plus own calculations.*
[2] *Source: REFUEL data (Deurwaarder et al., 2007), modified.*

As a consequence, major overall investments need to be made in 2nd generation biofuels. In the ACT Map scenario of the IEA Energy Technology Perspectives study (IEA, 2008), aiming at stabilization of global greenhouse gas emissions at 2005 levels, 2nd generation biofuels generate 550 Mtoe of biofuels by 2050 (or ca. 15% of total energy demand in transport). In order to reach this share, circa 4 trillion US$ of additional investments need to be made in 2nd generation biofuels up to 2050, a substantial share of the total 17 trillion US$ to be made in new energy technologies up to this year. Although impressive in absolute terms, compared to the baseline scenario the additional investment in biofuels represents an increase of ca 1.5% of total investments in the energy sector, or 0.1% of total global GDP over this period. Therefore, capital availability will only be a limiting factor if capital markets will be short already.

In terms of R&D investments, additional investments seem to be substantial: the ETP study estimates this to be circa 100 billion US$, mainly for the period up to 2035, so ca. 3 billion annually. Given most recent IEA (2007)data on government spending (indicating global R&D funding for biofuels in the order of 100 million US$ for 2005), this does require quantum leap increases in R&D efforts. Several countries, however, have indeed dramatically increased governmental R&D budgets for 2nd generation biofuels. In the US, for example, the Advanced Energy Initiative opened up 91 million US$ in 2006 and 150 million US$ in 2007 specifically for R&D on lignocellulosic biofuels (Neeft *et al*., 2007).

5.3 Costs of meeting a 10% biofuels target in 2020

An obvious and relevant question is what additional costs a 10% biofuels target for 2020 would imply in terms of additional costs compared with conventional fossil fuels. This question, however, is difficult to answer, for the following reasons:

- Long-term fossil oil prices are among the parameters hardest to predict in the world. Historically, hardly any projection of any centre of expertise has proven to be reliable. Therefore, a range of three possible oil prices has been analysed in this study.
- As many biofuel chains partly rely on fossil energy input (e.g. for fertilizer production or for agricultural management), biofuel production costs will increase with increasing oil prices. Some studies, such as by Hamelinck and Hoogwijk (2007) and the JRC/CONCAWE study (Edwards et al. 2006) have tried to take this into account, Uyterlinde *et al*. (2008) however have not.
- For all biofuels, essential feedstock will be purchased on commodity markets in which other sectors also influence prices. For 1st generation biofuels, this is particularly the food and feed sector, 2nd generation biofuels will start to interact with the stationary energy sector (biomass to power and/or heat) and other wood processing industries such as pulp&paper. Again, this makes long-term commodity prices relatively hard to predict.
- Particularly for 2nd generation biofuels, costs of conversion technologies are expected to decrease substantially in the coming decades. However, the extent and rate to which this cost reduction will take place is still highly uncertain.

Nevertheless, we made some indicative calculations on this issue, on the basis of future biofuel predictions of Hamelink and Uyterlinde, and with fossil oil price projections of 50, 100 and 150 \$/bbl (\$/€ exchange rate set at 1.4).

For this exercise, we assumed that the 10% biofuels target will be met by a mix of 60% 1st generation biofuels and 40% 2nd generation biofuels, referring to the October 2008 EP amendments of the EU RES directive proposal. For total road transport fuel demand in the Netherlands in 2020, the GE-HP scenario of the WLO (2006) was taken, assuming that 55% of fuel demand is diesel and 45% is gasoline. In order to use the data from Hamelinck and Hoogwijk (2007), we assumed that biodiesel feedstock would for 80% consist of rapeseed oil and 20% of palm oil; for 1st generation ethanol we assumed 40% wheat, 30% sugar beet and 30% sugar cane.

Table 4.2 shows the results of this indicative calculation in terms of total additional costs for the Dutch energy systems as a whole (or 'the Netherlands Plc'). Table 4.3 shows the same results, now translated into €cts per litre fuel sold.

Table 4.2. Indications of total additional costs (for 'the Netherlands Plc.') of a 10% biofuels target by 2020.

	Additional costs (Million €/yr)		
	50 $/bbl	100 $/bbl	150 $/bbl
Based on Hamelinck	334	-1	-336
Based on Uyterlinde	994	611	228

Table 4.3. Indications of additional costs (in €ct/litre fuel sold) of a 10% biofuels target by 2020.

	Additional costs (€ct per litre fuel sold)		
	50 $/bbl	100 $/bbl	150 $/bbl
Based on Hamelinck	2,0	0,0	-2,0
Based on Uyterlinde	5,8	3,6	1,3

Some critical remarks on these outcomes:

- The difference in outcomes between the Hamelinck and Uyterlinde assumptions clearly illustrate the significant uncertainty in future price indications, as specified in the bullet points above. However, both sources do not specify in detail which assumptions they have made regarding e.g. feedstock and conversion costs.
- As the biofuel costs by Hamelinck and Hoogwijk are substantially lower than those by Uyterlinde *et al.*, additional costs based on the former are also substantially lower. At an oil price of $ 150/bbl, calculated additional costs are even substantially negative. The difference between the two sets of biofuel prices clearly illustrates the difficulty in estimating them.
- It should be realized, however, that in practice biofuel prices will not dive below fossil oil prices as long as the lion's share of fuel supply, and thereby the price setting option, will be fossil fuels. If biofuel prices get close to fossil fuel prices, both fuel types start competing on price, regardless the biofuels target. If biofuel prices would go below fossil prices biofuels demand may increase to levels well over the 10% target, as long as there are no distribution and end-use barriers for higher shares. This will then lead to a direct response in (marginal) biofuel production costs.
- As biofuels production costs respond only moderately to oil price increases, a biofuels blend is a way of decreasing transport fuel price responses to higher oil prices. For example, taking the data from Uyterlinde, average prices of fully fossil fuels increase by 77% when the oil price doubles from 50 to 100 $/bbl. On the other hand, with a 10% biofuels blend, the fuel price increases by 58%. So on one hand, a 10% biofuels target leads to higher fuel prices (particularly at a low oil price), but on the other, a 10% biofuels target moderates the impact of oil price increases.

- Quite striking is also that an alternative assumption on the biofuels mix, viz. a 100% share of 1st generation and no significant break-through of 2nd generation, hardly affects the calculated additional costs for biofuels, neither under the Hamelink nor under the Uyterline assumptions. However, in terms of sensitivities of the outcomes, there are differences:
    - A projection with 100% 1st generation biofuels is more sensitive to variations in food commodity prices, while a projection with 40% 2nd generation biofuels is also (moderately) sensitive to woody and other lignocellulosic feedstock prices.
    - A projection with 40% 2nd generation biofuels contains larger uncertainties in terms of the investment costs for these installations, which are still relatively hard to assess.

Additional to this cost exercise, we tried to estimate the required investment costs in order to reach a 40% share of 2nd generation biofuels, as they are the key cost factor to this route. Solid data were not available, but a very simple translation of the IEA ETP indications (4 trillion dollars required for reaching 550 Mtoe of 2nd generation biofuel production by 2050) would result in 3 billion Euros of investments in the Netherlands to reach the 4% share of 2nd generation biofuels in 2020. However, this approach does not take into account the complexities of technology development (in which initial installations always require most investments), and the dependence of the Netherlands on global efforts on 2nd generation technology development.

5.4 Long-term issues relating to investments in biofuels

Relating to investments in biofuels, the question arises to what extent biofuels will fit into the long-term energy economy. Here we focus on two questions: whether there will be a long-term market share for biofuels, and to what extent investments in 1st generation biofuels may introduce a lock-in effect hampering introduction of 2nd generation biofuels[6].

First, the question may be asked whether the long-term perspective for biofuels is sufficient to defend major short-term investments in the technology. In due time, alternatives such as the (plug-in) hybrid, the all-electric vehicle and the hydrogen-fuelled fuel cell vehicle may enter the market and become competitors to biofuels. However, studies such as the ECN energy vision to 2050 and the IEA Energy Technology Perspectives (ECN, 2007; IEA, 2008) do foresee a long-term sustaining role for biofuels, particularly in sectors such as aviation and long-distance heavy road transport, for which the alternative technologies are not particularly suitable. This implies that particularly biofuel technologies that produce middle destillates (kerosene and diesel), such as the FT process, will probably be able to maintain a position in the market, even with a strong take-off of the electric of fuel cell vehicle. Aviation and truck transport together amount to ca. one half of the transport sector's energy demand (Mantzos and Capros, 2006), so this will remain a substantial market.

Second, the question whether investments in 1st generation biofuel technologies may work as a barrier for the introduction for 2nd generation biofuels. Here, it is important to differentiate between ethanol and biodiesel production. As for 1st generation ethanol production facilities, these can be retrofitted into 2nd generation facilities if the corresponding technologies become available. After all, the essence of 2nd generation ethanol is that the sugars for the fermentation process are first produced by the hydrolysis of cellulose. In fact, existing ethanol plants can gradually shift towards second generation by introducing and expanding a cellulosic hydrolysis line, and correspondingly diminishing inputs of conventional crops like wheat or sugar beet. So in short, investments in 1st generation ethanol plants might work as a step-up for 2nd generation ethanol, as long as facilities introduced are 'lignocellulose-ready', e.g. by reserving space for a later to build cellulose hydrolysis line.

As for the diesel replacers, there is no technology link between biodiesel production and FT-diesel. Therefore, investments in biodiesel may become a barrier for introduction of 2nd

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[6] We do not go into the uncertainties related to future transport energy demand in general: although this indication also varies between studies, it is clear that transport energy demand will remain a substantial grower in the future.

generation biobased diesel replacers. On the other hand, 1st generation biodiesel production costs consist for only ca. 10% of investments in the production plant, so this is no major obstacle. Additionally, as long as biofuels targets keep increasing, additional biofuels demand may be met by 2nd generation biofuels without reducing existing 1st generation capacity. Overall, these lock-in effects seem to be relatively modest.

6 Mandatory mixing of biofuels – the economic perspective

General remarks

6.1 General remarks

How does a mixing mandate with respect to biofuels impact on Cramer's sustainability criteria (see Chapter 1)? What is the "price" of a 10% biofuel blending obligation in terms of biodiversity, hunger, greenhouse gas emissions and the price of food? To answer such questions one needs to integrate biophysical and socio-economic modelling. Knowledge of price effects, and associated behavioural changes of both producers and consumers, is necessary to accurately predict changes in land use, production levels and consumption patterns.

The price of biofuels is linked to the price of fossil fuels. First, and obviously, this is because (fossil) fuels are an input in the production of crops, affecting production costs. More importantly, biofuels and fossil fuels are substitutes on global energy markets – enhanced scarcity (and higher prices) of one fuel type triggers extra demand (and higher prices) for the competing type. This means that the recent increase in the price of fossil fuels has contributed to higher prices of biofuels. Since the first (=current) generation of biofuels depends to a large extent on food crops, the price increase of biofuels in turn contributed to rising food prices. Not only are food crops used as fuel rather than as food (a direct effect), it is also the case that a larger share of agricultural lands is allocated to growing 'fuel crops' – reducing supply and raising prices of other crops – which is an indirect effect. When extra production of fuel crops takes place on lands that would otherwise not be cultivated, there are negative consequences for biodiversity conservation and GHG emissions, as explained in Section 1.3. Work of Joseph Schmidhuber (2006) (Food and Agricultural Organisation of the United Nations) relates the competitiveness of various "feed stocks" to the price of fossil fuels, deriving parity prices for which biofuels become economically viable sources of energy (Figure 5.1). Parity prices according to the figure range from USD28/barrel of crude oil for cane producers in a southern region in Brazil to almost USD100/barrel for European BTL producers ("biomass to liquid"). This information can be used to predict the expansion of certain farming systems, which in turn may be related to crowding out of food or conversion of habitat.

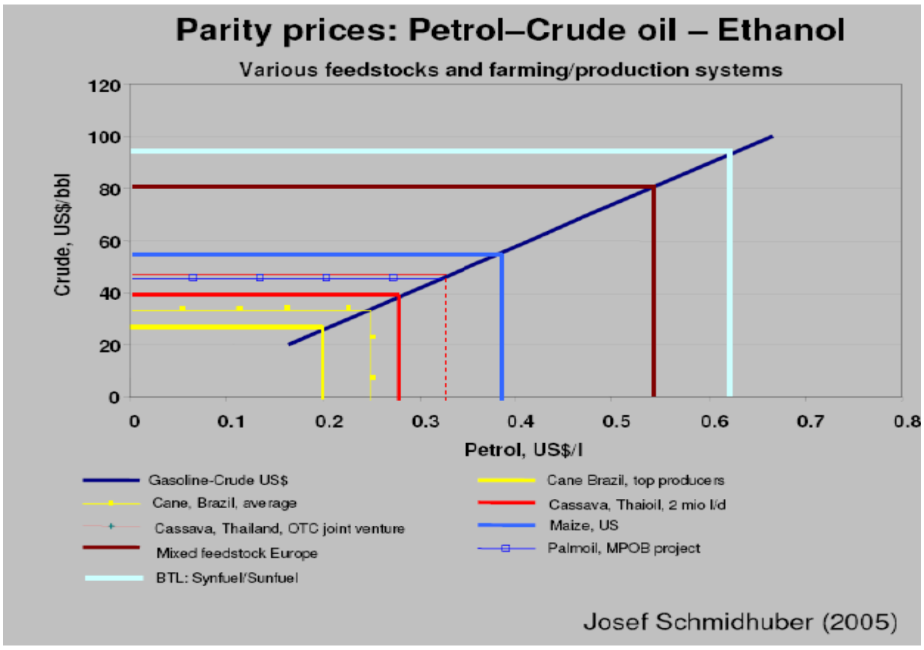

Figure 5.1. Parity prices for various first generation feedstocks. Source: Schmidhuber, 2006.

Energy markets are large compared to agricultural markets, hence demand for fuel defines a perfectly elastic demand curve for energy crops – farmers can supply arbitrarily large quantities to energy markets without adversely affecting prices. In essence, this defines a price floor for energy crops, which could potentially limit the relevance of "Cochran's treadmill" (created by the combination of inelastic demand for food and ongoing productivity growth in agriculture), and its implied gradual deterioration of the terms of trade for agricultural products. Due to the indirect land-use effects mentioned above, energy markets also support prices of non-energy crops. By creating a floor price for agricultural crops, energy markets may be viewed as a new intervention system that could potentially stabilize food prices. In Brazil, for example, the large ethanol market has stabilized the price of energy crops. The effect of (mandatory) mixing on price volatility is obviously relevant for both consumers and producers/investors, but is largely beyond the models discussed below. Partial and general equilibrium models focus on equilibrium outcomes and long-term price impacts of specific policies, and do not incorporate short-term price dynamics or real-life shocks that might temporarily disturb markets. Nevertheless, since such shocks have welfare implications in real life, it is good to know whether we may expect volatility to be accentuated or attenuated when food and energy markets are linked.

However, two caveats are relevant regarding the price stabilizing role of agricultural products. First, energy markets themselves are volatile, and therefore do not create a "stable" price floor. Second, the potentially stabilizing role of energy markets depends on the nature of the biofuel policy, in particular whether biofuel use is mandatory or not. When markets govern the use of biofuels (i.e. use more biofuel when agricultural crops are relatively inexpensive, and less when the reverse is true), the price floor effect implies a stabilizing role. In contrast, mandatory mixing forces a strong link between food and energy markets that could potentially be destabilizing, contributing to price hikes of food. This is the case because energy cannot be directly converted to food (even if the reverse is true). Hence, mandatory mixing implies enhanced demand for food, even in times of scarcity and high food prices, which may contribute to further price hikes. This is an issue that warrants additional analysis.

Perhaps the most striking feature of the 2008 food crisis has been the adverse impact of high food prices for the world's poor. The net outcome of higher food prices on welfare of households depends on whether they are net consumers of food – consume more than they produce. A large share of the world's poor, even in rural areas, are net consumers and suffer from rising food prices (at least in the short run, when technologies and infrastructure are fixed).
High food prices may contribute to hunger. The purchasing power of certain social groups may be so low that it is impossible for them to satisfy their basic demand for food. In biophysical analysis, such outcomes are sometimes taken on board by augmenting "market demand" with an extra source of demand for food referred to as "non-economic" demand. This reflects the concern that to properly feed the world's poor one should produce more food than dictated by the free hand of the market (or, alternatively, distribute available food differently).

It would be too simplistic to state that biofuel expansion is the main culprit of the recent increases in food prices. For example, global consumption of wheat and rice has exceeded global production for 6 out of the 7 past year, implying that global wheat and rice stocks have been drawn down to precariously low levels. To carefully identify the contribution of biofuels to food price hikes one needs to develop a model. According to one IFPRI study, the contribution of biofuel demand to increases in grain prices from 2000 to 2007 is about 30% (Rosegrant, 2008). That is: recent biofuel expansion may be an important determinant of rising food prices in the short-term, it does not appear to have been an overwhelming force. But this may change in the future as expansion rates accelerate – in response to policy initiatives, or otherwise.

Other studies suggest smaller effects for most food commodities (Banse et al. 2008) or larger price effects (World Bank, 2008). There are multiple explanations for such differences, including a focus on different time periods or crops, or the currency in which price effects are expressed (and whether prices are included in real or nominal terms). One prominent explanation is different perspectives on the role of speculation and trade measures, and whether such actions can be attributed to the use of crops as biofuel (changing the fundamentals of agricultural markets), or not.

To determine the effects of mandatory mixing policies on the poor one needs to make assumptions about the development opportunities implied by enhanced market demand and higher prices. In particular; will demand be satisfied via large-scale plantations or via small-scale farms? Economies of scale in production and procession will be an important factor in this respect, implying that the development opportunities are probably crop and region specific. If production of energy crops takes place on large-scale plantations, analysts need to consider the implications in terms of demand for labor and wage effects, and potentially consider the fate of displaced households. Moreover, institutional constraints may be relevant. For example, ownership of (formal) land titles may be required to fully benefit from opportunities provided by extra demand for energy crops. Indeed, it is conceivable that displacement of households lacking such titles may occur, to facilitate the expansion of plantations.

While production costs of some biofuels are low enough to render such fuels competitive (think of Brazilian ethanol production from sugar cane), the same is still not true for maize-based ethanol in the US and rape oil-based biodiesel in the EU. In the US and EU, public support and regulation are necessary to promote the switch to biofuels, which involves welfare losses. The EU has announced blending mandates, which require minimum shares of biofuels in the transport fuel market. This raises the price of fuel, the cost of which are borne by consumers who pay a higher price for the goods they consume (a transfer). Consumers also “pay” because they consume smaller quantities (an efficiency loss). In addition, producers lose as they sell smaller quantities (again; an efficiency loss). Public support may also come via budget support (subsidies) and trade restrictions (import tariffs). Taken together, policy support is very important. Removing it for biodiesel in the EU is predicted to shrink production levels by more than 80%. Based on an evaluation of current policy initiatives in the US, EU and Canada, the OECD estimates the total costs of biofuels support USD 25 billion per year for the period 2013-2017. In terms of the price per ton of GHG (CO_2 equivalent) saved this amounts to USD 960-1700, which is high when compared to the costs of alternative means to limit GHG emissions. For example, a recent study of the costs of carbon sequestration in the United States (which is not necessarily the most cost-effective location from a global perspective) arrives at a range of cost estimates of USD 7-22 per ton of CO_2 equivalent (where we should note that these costs should go up as more land is allocated to the production of trees as the opportunity costs of land increases – as in the energy crops case). It appears as if promotion of biofuels is an expensive way to reduce net emissions of greenhouse gasses.

A blending mandate artificially creates demand for biofuels, raising prices of agricultural output that may be used as fuel. Obviously, these impacts are more pronounced as a greater share of the world’s output is affected – a Dutch policy of going alone will have negligible effects compared to EU-wide policy initiatives. Rising prices of agricultural output encourages (i) the conversion of food crops into fuel, which raises food prices, (ii) more intensive agricultural practices to increase supply in response to higher prices, (iii) expansion of the agricultural acreage at the expense of other uses to increase supply in response to higher prices, and (iv) technological innovations in the biofuel sector. Preferably, (i)-(iv) should be included in a dynamic partial or general equilibrium model. Currently, no study does all of this. Currently, no study does this. The technical studies reviewed in this report lack all these components. The various economic models (IFPRI, LEI, OECD) include linkages (i)-(iii), but not (iv) which means that the costs of supplying biofuels in the long term is probably overstated. However, technology switches are sometimes incorporated via *ad hoc* assumptions in a sensitivity analysis (“what happens when 2nd generation technologies are available after 2015?”). In addition, the models may be incomplete in the sense that by products of energy crops may be useful as feedstock of livestock, such that a multi-market set-up would be more appropriate than a focus on energy only.

Before discussing the assumptions and outcomes of the three models, a few general observations are noteworthy:

- The IFPR (2007) and OECD (2008) studies compare the joint effect of EU and US biofuel expansion studies and do not consider the EU blending mandate in isolation. Let alone that Dutch plans are separately modelled… The GTAP-E model focuses on the EU policy and allows more precise identification of the consequences of the blending mandate.
- The effects of biofuel support policies depend crucially on assumptions with respect to:
    - The share of land allocated to fuel crops that comes at the expense of food crops, and the share that comes at the expense of "fallow land;"
    - Developments in the 2nd generation-type technology, and the speed of adoption and diffusion of this new technology;
    - The degree to which trade in fuel crops and biofuels is allowed across EU and US borders;
    - Exogenous changes in the price of oil, as higher energy prices trigger additional usage of agricultural products as fuel; and
    - Specifications of functional forms of equations in the model and selection of key parameters. Some choices have been informed by a limited amount of data, suggesting there is scope to disagree about the details and calibration of models.

It is also important to note that changing food prices may affect the "rich" and the "poor" differently. Specifically, even modest price increase can have adverse effects on food security for the poor in developing countries, who are exposed to greater risks in terms of food prices than the rich. The poor allocate a greater share of their income to foodstuffs. Also, the costs of the raw food material (i.e. excluding packaging, retailing etc.) as a share of the total price of food are greater in developing countries than in developed countries, and therefore price increases of raw material matter more. Moreover, the poor typically consume goods that are projected to experience price increases that are relatively large (cereals and roots versus dairy and meat). Taken together: the OECD concludes that "the higher prices for basic food commodities represents a substantial threat to low-income consumers in developing countries. IFPR researchers make similar statements (e.g. von Braun 2008). Of course, higher food prices also represent additional income opportunities for some of the world's (rural) poor. As mentioned above, a distinction should be made between net exporters and net importers of food (at the national as well as the household level), and the development prospects are partly determined by the scale at which production of energy crops will take place (plantation-style or accommodation within existing farming styles).

Because of these inherent uncertainties, one should not take precise predictions of any model too literally. Nevertheless, model simulations can be useful to indicate the contours of future development and give a sense of "ballpark" magnitudes. The LEI study (Banse *et al*., 2008) is based on a general equilibrium model – taking feedback effects via non-agricultural markets into account – whereas the IFPRI and OECD model are partial equilibrium models, attempting to model the agricultural sector only (taking the rest of the economy as "given"). Interestingly, it appears as if, in spite of the distinct modelling approaches, the modelling strategies pursued by IFPRI, OECD and LEI produce rather similar ballpark estimates.

6.2 IFPRI

Model outline

IFPRI uses the IMPACT-WATER simulation model to explore the consequences of biofuel expansion for food markets and various environmental indicators. IMPACT-WATER is a partial equilibrium model that distinguishes between 281 geographical units and the 40 most important agricultural commodities produced in the world. Within each unit (country or regional sub-model), supply, demand, and prices for agricultural commodities are determined. These country and regional agricultural sub-models are linked through trade, resulting in a system of equations on food that can be used to analyze baseline and alternative (policy) scenarios. The heart of the model is a system of supply and demand functions that incorporate supply and demand elasticities, which determine world agricultural commodity prices annually at levels that clear international markets. In other words, free trade (price equalization) is assumed in the baseline model. One nice feature of the model is the explicit inclusion of a module that extensively analyzes water availability as a driving variable of agricultural production. Water flows and storage have an influence on food supply, and hence on demand and prices.

Main Results

Based on actual plans (policies), new developments in supply and demand as well as new biofuel investment plans, the IMPACT model predicts that, compared to a scenario where biofuel production is “frozen” at the 2007 level, the prices of cassava, maize, oil seeds, sugar and wheat in 2020 will go up by, respectively, 11%, 26%, 18%, 11% and 8%. Doubling the levels of biofuel use (more drastic expansion rates) obviously imply more pronounced price effects; respectively 27%, 71%, 44%, 27% and 20%.

One nice feature of the IFPRI model is that it explicitly accounts for one prominent dimension of poverty – it enables an analysis of the consequences of biofuel expansion on food security. Specifically, the model looks at caloric consumption in various parts of the world and at the number of malnourished children. For example, the model results indicate that, for Sub-Saharan Africa, caloric consumption will decline by 4% in the moderate scenario, and no less than 8% for the drastic biofuel expansion scenario (consequences for other regions are also significant, but less pronounced – see Figure 5.2). Increased expenditures on expensive food come at the expense of other badly needed commodities and services (housing, transport, education). Implications for households in countries like Bangladesh can be tentatively analyzed.

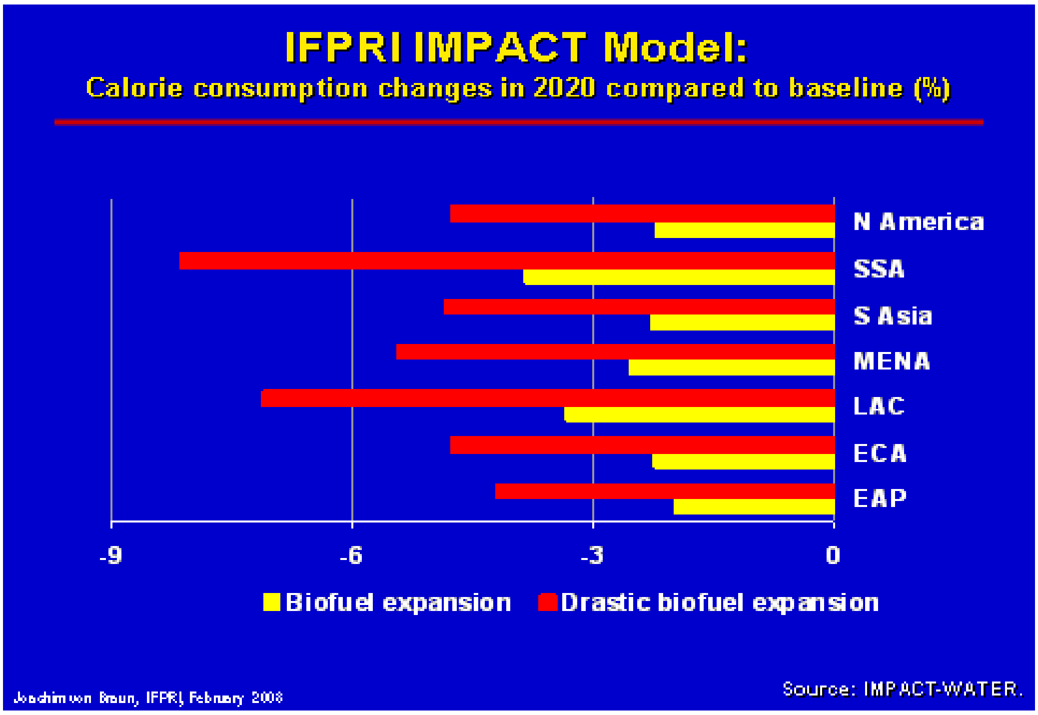

Figure 5.2. Changes in caloric consumption for various regions as a result of biofuel promotion policies Source: IFPRI 2007.

6.3 OECD

Model outline

The OECD uses the so-called Aglink-Cosimo model to analyze market impacts and landuse change. This is a medium-term simulation model for agricultural markets in developed and developing countries. It is a partial equilibrium model of domestic and international markets, with detailed mapping of various agricultural policies, and provides a complete picture of the biofuel chain. It includes extra components, including investments in production capacity (irreversible investment), and production of side products as distillers grains and oilseed crush. The paper includes a rudimentary representation of 2nd generation technologies (and derived extra demand for crops via their residues), but this technology is not included in the baseline for the first decade as it is expected to be commercially uninteresting then. It is assumed that crude oil is in the USD90-104 range.

Main results

The model is used to explore the consequences of current biofuel policy initiatives in the US and EU in terms of land use and food prices. Compared to the IFPRI study, the model predicts that biofuel support policies have more modest consequences in terms of rising food prices. International prices for wheat, coarse grains and oil seeds increase by, respectively, 8%, 13% and 7%, relative to a scenario without biofuel support policies. Following the strong increase in biodiesel production, however, prices for vegetable oils are expected to increase by 35%. Land used for the production of energy crops is expected to increase by almost 13 million hectares, or an increase of 1.5%. More than 2 of these million hectares will be located in Africa.

Large-scale adoption of second generation biofuel production technologies – combined with extensive amounts of croplands used for 2nd generation fuel biomass – would mitigate this price increase, and have major regional implications. Presumably 2nd generation technologies would be at the cost of environmental objectives (as production on current agricultural lands is intensified and extra land – potentially environmentally sensitive lands, in Europe and abroad – is taken in production). Recent studies emphasize that land use changes that include CO_2 releases due to burning or microbial decomposition can offset the potential gains in terms of reduced GHG emissions.

6.4 WUR-LEI

Model outline

The GTAP model is a general equilibrium model (with endogenous demand for energy, developments in the crude oil market, and exchange rate linkages) that simulates production, consumption and bilateral trade of key commodities at the global level – a multi-region and multi-sector model. To include biofuels in the GTAP model a multilevel structure is developed where fuel crops are used as intermediate inputs in the petroleum sector (biofuels are not modelled as a separate sector). The EU blending mandate is captured by subsidizing the petroleum industry to use biofuels (financed by an end user tax of petroleum use). Compared to the standard GTAP model, adjustments were made to better describe effects via land markets (e.g., better modelling substitution of land types for various uses, inclusion of a land supply curve).

Main results

The model is used to simulate two scenarios: mandatory blending of 5.75% and 11.5% in 2010, and therefore aim to predict medium-term effects rather than long-term effects as in the IFPRI and OECD study (which consider the year 2020). In the absence of biofuel policies, Cochran's treadmill implies deteriorating terms of trade for agricultural commodities – approximately 4% per year for cereals and sugar, and 1.75% for oil seeds. Relative to this benchmark scenario, prices are higher with EU biofuel policies in place. Specifically, in the modest scenario (5.75% mixing), the price of oilseeds is predicted to increase by 4% and by 10% in the ambitious scenario (11.5% mixing). As European farmers switch to the production of oil seeds, demand for biofuels in the ambitious scenario pulls up the prices of other agricultural commodities. The price of cereals increases by some 6% relative to the no-policy scenario, and sugar prices increase by 10%. Extending the partial equilibrium models above, this general equilibrium model also captures changes in the oil price due to enhanced consumption of biofuels. Unlike expectations of other modellers (who argue that energy markets are large relative to agricultural markets so that farmers face a perfectly elastic demand curve for their energy crops), the LEI study predicts that crude oil prices will fall by some 2% relative to the no-biofuel-policy scenario. Combined with more expensive fuel crops, this triggers a fall in the consumption of biofuels in non-European countries such as Brazil (partially offsetting gains in GHG emissions in Europe). Specifically, the share of biofuels in Brazil fall by 7% and 15% in the modest and ambitious scenario, respectively. While the EU becomes an important importer of biofuels, the price of biofuels remains higher than the price of crude oil. To achieve the blending targets, consumption of biofuels is subsidized (which must be financed out of a tax on petrol – budget neutrality). As a result, petrol prices will increase by 2% and 8% in the modest and ambitious scenario, respectively. On average, the subsidy rate in the EU to achieve price parity is some 50% in the ambitious scenario.

Overall assessment

Mandatory mixing with biofuels is a relatively expensive way to mitigate the greenhouse effect – the costs per ton of carbon avoided appear to exceed by far the costs of alternatives. However, such cost estimates are incomplete as they ignore effects in other markets, such as the one for food. We have reviewed three models to shed light on this issue. They produce outcomes that are not inconsistent, predicting that the mandatory mixing initiative will result in (i) expansion of the area allocated to agricultural production (and production of fuel crops in particular), and (ii) increases in the price of crops that may be used as an input in biofuel production, and possibly food price increases across the board. The magnitude of the price effects seems comparable as well. The different models have their strengths and weaknesses. The LEI model is able to capture general equilibrium effects (via exchange rates and oil markets, for example), describes some elements of the EU common agricultural policy, and captures trade flows (and EU trade policies) in the most sophisticated way. In contrast, the IFPRI study best describes world-wide agricultural production, and links the model outcomes to issues like poverty and malnutrition. The OECD model best captures the intricacies of the biofuel sector. In light of the differences (indeed: complementarities) it is encouraging to see that the main message is consistent: the blending mandate comes at the cost of moderately higher food prices, somewhat increased poverty, and reduced biodiversity.

7 Synthesis

7.1 Context

This study has looked into the expected near future developments in the biofuels sector to assess the availability of sustainable biofuels for the Netherlands in 2020 and the implications for sustainability components as outlined and accepted by society at large in the Cramer criteria by the Netherlands government.

The European commission has proposed an integral approach for reducing GHG emissions and increasing energy security by aiming at 20% renewable energy by 2020. Bio-energy is proposed to make a contribution of about $2/3^{rd}$ of this target for heat and electricity (equivalent of 180 Mtoe; ± 7.5 EJ). The EU policy further aims at an obligatory target of for the transport sector of 10% by 2020 (equivalent of 30-40 Mtoe; ±1.45 EJ), for which the precise feedstock is still to be specified. The Netherlands government pursues this target of 10% obligatory blending in transport fuels in 2020 and even considered 20%. Here, biofuels have been considered only.

In addition, biofuels production is assumed to contribute to rural development, supporting agricultural producers in OECD countries, and to create an opportunity for development of developing countries to reduce hunger and poverty.

A fierce debate about the sustainability of biofuels has developed over the course of 2007, as the rush for energy crops might have contributed to the unprecedented increase in number of food insecure people while benefits for greenhouse gas reductions are unclear. Sustainability criteria for biofuels are being developed currently, implying that;

- A certain percentage of greenhouse gas reduction should be attained compared to use of fossil fuels.
- Competition with food should not endanger food security and other local applications of plant biomass, e.g. medicines.
- Protected or vulnerable biodiversity may not be affected.
- The quality of soil, air and water must be sustained.
- Biofuels production must contribute to local welfare.
- Biofuels must contribute to the well-being of employees and local population.

So far, various studies have been performed to estimate the potential global production of biomass for biofuels in the far future, not focusing on the implementation of policy goals. Whereas these approaches attempt to account for several biophysical criteria like direct and indirect land use, they lack mechanisms to consider economic drivers that might lead to options not congruent with biophysical options. Agro-economic models, like the OECD-FAO, World Bank, IFPRI and WUR-LEI, do consider economic aspects and allocations to specific markets and locations. Our review revealed that they do not explicitly consider sustainability criteria, with some exceptions like child undernourishment as an indicator for food insecurity by IFPRI. Also, technological innovations, that are of eminent importance in the development of an emerging sector, can not be well mimicked.

For assessing near future development and for evaluating sustainability, in this study, we have therefore pursued an approach to identify the most relevant and interacting processes that will determine the evolution of the emerging biofuels sector. Whereas no straightforward conclusions about the overall developments can be made because of the uncertainties in each process, this does not imply that conclusive statements cannot be made for individual components of the overall development, and that evaluation of sustainability criteria would not be feasible.

The chart (Figure 6.1) sketches the most important components to be considered. First generation biofuels are produced from food commodities and put a claim on food and natural resources that in turn affects food security and poverty, and GHG emissions. Second generation biofuels utilize waste and residues and, food and non-food biomass with somewhat different claims and effects though principally similar to food-based biofuels. The magnitude of these two flows will depend on the rate of technology development of the various components, primarily conversion technology addressed in chapters 3 and 4, and agro-technology, dealt with in chapter 2. The implications for costs and price developments for biofuels, food security and development have been elaborated in chapter 5.

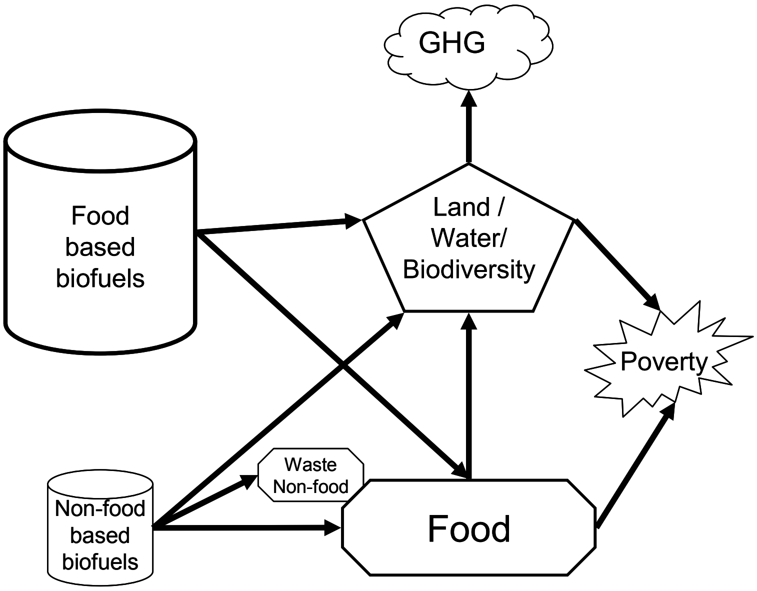

Figure 6.1. Simplified relation linking the emerging biofuels sector to expected consequences for evaluating the sustainability of biofuels by 2020.

This chapter synthesizes the information presented in chapter 1 to 5 and sketches the uncertainties in the development processes and identifies robust conclusions with regard to the sustainability of biofuels. Finally, two possible perspectives are presented on the impacts of Dutch mandatory mixing policies in 2020 on various sustainability criteria. These are not intended as scenarios for specific parameter configurations. Rather, these perspectives are intended to explore the width of the range of potential outcomes, and they reflect diverging opinions on the net impacts of large-scale expansion of biofuels usage. In light of the considerable uncertainty regarding key mechanisms and parameters, no specific perspective is endorsed.

7.2 Major uncertainties

Projected agricultural productivity

Globally, agricultural productivity has developed very different per world region (Figure 6.2). The reasons for different developments are plentiful (Chapter 2), signalling important uncertainties to what extent future developments in productivity may occur. Theoretically, large yield gaps still occur in many world regions (especially in developing countries). However, the closure of these yield gaps is not straightforward. Without a production-ecological approach that estimates the effect of local conditions on production possibilities and without an assessment of the underlying driving forces that can make the necessary resources for production (increase) available in the future, it will not be feasible to estimate accurately where the production will level off, what the costs are in terms of necessary investments and whether the rate increase from the past can be extrapolated to the future. This explains large differences in future yield projections in many global projections (Figure 6.3).

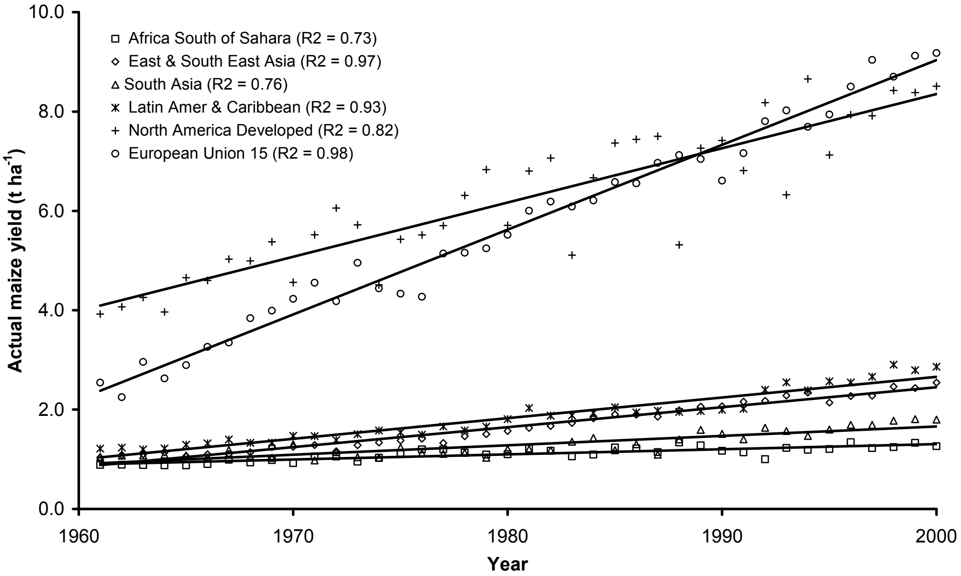

Figure 6.2. Yield increase over the past four decades in 4 global regions (Bindraban et al., 2008, based on FAO data).

One of the crucial questions is the rate of change that is possible in the coming years until 2020. Agro-economic models (as explained in Chapters 2 and 5) use price-response relations in addition to the future trends estimated by FAO. With higher crop prices in the future a higher yield increase is estimated by most of the agro-economic models, based on intensification investments. However, these intensifications are based on elasticities determined by historic developments in yield changes and, it is uncertain whether these elasticities will remain valid in the future when food price levels might be structurally higher. Additionally, the involvement of the energy sector in agriculture might change the fundamentals of the markets, investments and yield changes. Furthermore, the biophysical world behind these yield increases is not affecting these outcomes. For example, water availability is one of the producing factors influencing potential changes in yield increases. Attempts to improve water productivity in agriculture face substantial agro-technical challenges and slow implementation rates because of the many socio-cultural and economic modifications required. Climate change is expected to exacerbate the adverse conditions in regions that are in the greatest need for productivity increase, causing increasing uncertainties in achievable yields.

Another production factor determining yield increases is nutrient availability. Soil organic matter is a major determinant of soil quality. Loss of soil organic matter occurs when the input of fresh organic material declines, e.g. by removal of crop by-products, and also after clearing of natural lands or grassland for conversion into arable land. Increasing soil fertility under less favourable conditions generally is a long-term process where the combined application of external nutrients through organic matter and artificial fertilizer gives the most promising results to increase crop yield. These complex eco-physiological interactions and the economic and institutional aspect of facilitating fertilizer use are not adequately analyzed in the reviewed studies. Some studies have incorporated the price of fertilizer, but it is unknown whether the fertilizer price development and associated application of fertilizers match the projected higher yields in the future that will generally need more fertilizers. This aspect adds further uncertainties in the expected yield increases until 2020.

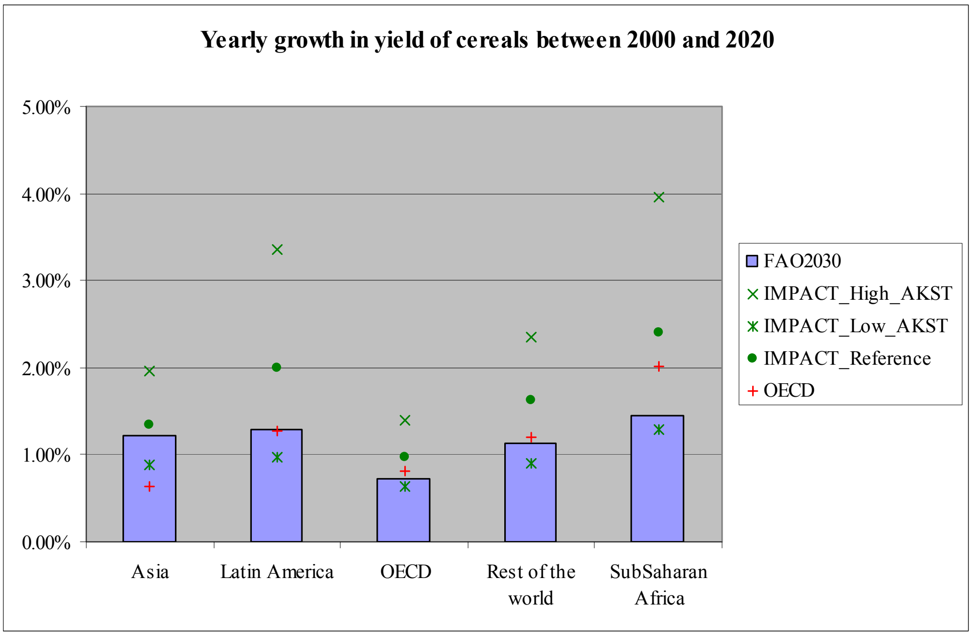

Figure 6.3. Estimated cereal yield increase in various regions of the world until 2020, according to different assessments (PBL, 2008).

Clearly, installation of favourable institutional conditions such as support to research and extension, and new agricultural industry for producing mechanical equipment and agro-chemicals, provided the conditions in the past for the technological innovations that boosted agricultural productivity. These circumstances are crucial as to be able to simulate yield increases. So far, these aspects are not included in different model efforts. Especially on the short -term these factors may lead to lower yield increases than expected when yield gaps are considered or simulated by agro-economic models.

Availability of land for biofuels and use of marginal land

Future availability of land for biofuels is dependent on future projections of food and feed demand and the expected yield increases (see above). Future demand for food and feed depends largely on income growth which is difficult to predict and therefore demand projections are highly variable. As an example, the estimated global production of 227 million tons of soybean in 2020 by the IFPRI, has already been produced more than 10 years earlier (2006/7) by a total production volume of 235 million tons, which means that the demand for soybean was underestimated. Overestimation may also occur if future economic growth is less than assumed.

The availability of marginal land, usually identified as a major source of land for bioenergy, is highly uncertain. Again, the rate of change that is required to make marginal land available for bioenergy is time-dependent. Marginal lands are generally beset with a range of biophysical limitations, such as low and variable rainfall often with prolonged periods of drought, poor soil quality in terms of fertility, texture and structure and occasionally yield depressing or toxic conditions such as high salinity, high levels of aluminium or iron, etc. Also, unfavourable socio-economic conditions lead to low levels of intensification and capitalization of farming operations and may reduce opportunities for productivity enhancing measures, e.g. in cattle ranging in Latin American countries. These limitations cast serious doubts whether realization of yield increases are possible in short periods of time. Especially, since investments, biophysical, infrastructural, institutional and financial constraints are higher compared to more favourable agricultural lands.

The generally preferred way to match the increasing food and feed, and bioenergy demand is a further increase in crop yields above the levels projected by the FAO. The recent OECD environmental outlook states that for limiting the temperature rise to 2°C we need a global yield increase of 1.6% per year instead of an average of 1% as predicted for the baseline scenario.

This is feasible but not easy since it would require a break with historic trends. Moreover, land is relatively cheap, for parts of the world. If land is cheap relative to the other production factors, part of the increased demand will be supplied by an expansion of agricultural lands, as happened in the past in e.g. South-America. Higher prices for crop products in those regions in the future will not only stimulate yield increase but also land expansion if the cost ratio between land and the other factors remain as they have been in the past. These uncertainties explain the different projections of land expansion in the several global environmental assessments (Table 6.1).

Table 6.1. Estimated amounts of global agricultural land use in 2020 due to the increasing demands, according to different assessments (in billion km2; PBL, 2008). The impact of obligatory targets for biofuels have not been included in these figures.

	2000	OECD Environmental Outlook	Agricultural Assessment (IAASTD)	FAO Agriculture Towards 2030
Arable land	15	18	18	17
Pasture land	33	36	37	33
Total agricultural land	49	55	56	51

These uncertainties with respect to the availability of land and land use also applies to specific regions, like the EU. Several studies (both agro-economic studies and potential studies like REFUEL and the EEA study) make use of different estimates of land availability within the EU. Clearly, these different values are dependent of the assumed share of 2nd generation biofuel, the openness of the European agricultural market (dependent of changing Common Agricultural Policies), the assumed competitiveness of the European market, the fossil fuel price and assumed changes in yield (Chapter 3).

Availability of residues

Not many studies have paid explicit attention to the availability of residues. On the longer term, residues are assumed to play an important role in the total portfolio of bioenergy options. The use of residues from agriculture does however imply a trade off with regard to the fertility of soils and maximum removal amounts will be highly dependent on location specific conditions (Chapter 2). Changes in soil carbon and fertility should be accounted for when calculating greenhouse gas balances. The use of residues from forest and food chains might become an important source of feedstock mostly for 2nd generation biofuels, but competition with the current use of these residues should then be taken into account and displacement effects on e.g. GHG emissions should be assessed. So far, not much research is available for these aspects of residues.

First and second generation of biofuels

The current production of biodiesel and bio-ethanol is all classified as first generation. The second generation alternative for biodiesel would come from Fischer-Tropsch (FT) diesel and for bio-ethanol from ethanol produced from ligno-cellulosic feedstock.

The second generation plants currently under development are mainly ethanol plants using lignocellulosic feedstock. Globally there is a rapidly increasing interest in cellulosic ethanol (Figure 6.4). Most important initiatives in FT-diesel seem to originate in Europe. FT-diesel plants do not have the advantages as in bio-ethanol production in terms of feedstock, interlinked technologies and gradual investments, but require large-scale initial investments (Chapter 4).

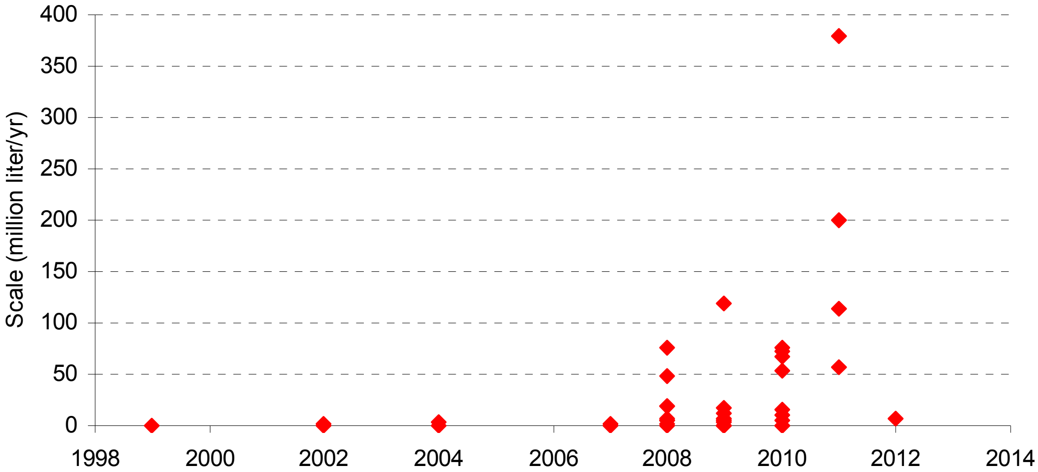

Figure 6.4. The scale and starting date of different second generation ethanol plants established and in planning up to 2012, primarily installed in the USA (Hamelinck and Koop, 2008).

Stimulation of second generation biofuel is dependent on investments in research and development, enhancement of large-scale supply chains as second generation biofuels benefit from large scale because of the high investment costs and the harmonisation between sectors including energy, agriculture and industry to reduce the risk for farmers to switch to lignocellulosic feedstock. Therefore, it is highly uncertain what the share of 2nd generation biofuels will be by 2020.

Clearly, second generation biofuel technologies are more dependent on stability in the investment market due to the innovativeness of the technology and the higher susceptibility to booms and busts in biofuels markets. As Figure 6.5 illustrates, capital costs consist of a relatively minor share in production costs for 1st generation biofuels, while it makes up more than 50% of production costs for 2nd generation biofuels (Chapter 4).

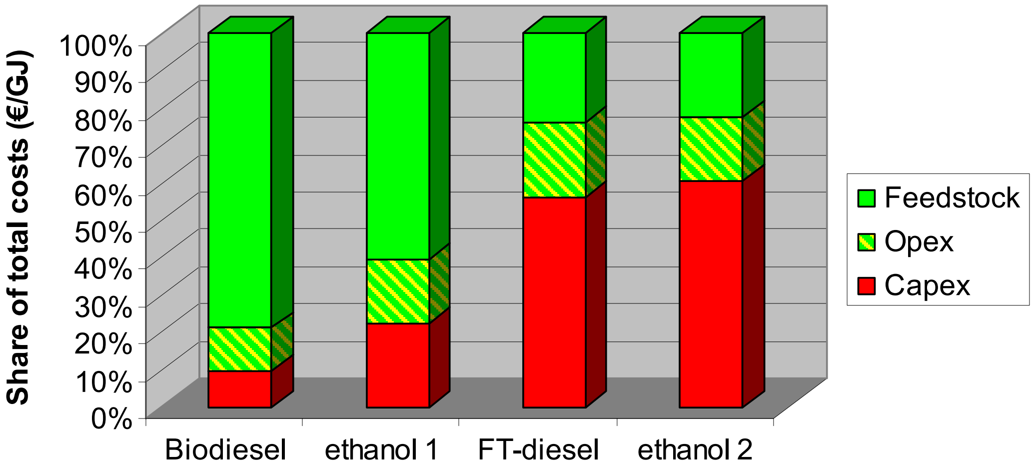

Figure 6.5. Relative shares of feedstock costs, operational expenditures (Opex) and capital expenditures (Capex) in total biofuel cost price for different biofuels (Londo et al., 2008).

Environmental consequences

The discussions on environmental consequences focus on land use (biodiversity) and greenhouse gas emissions (Chapter 1). Furthermore, intensification can also have other adverse (local) environmental consequences, like increased water use and emissions from agriculture that negatively affect surrounding ecosystems. These effects need to be assessed and in some situations extensification rather than intensification of agricultural production may be preferred which has implications for crop productivity.
Changes in GHG emissions within the production chain (direct emissions) differ because of different calculation methods in the Life Cycle Analysis of using biofuels (Chapter 3). Important aspects to be considered in the LCA analysis are the type of conversion routes and feedstock included, the allocation principle used for by-products, the main data assumptions and the system boundaries. Results for direct greenhouse gas reduction compared to fossil fuel are summarized in Figure 6.6. These estimates assume good agricultural practices, though in practice poor management occurs as well with increased, rather than reduced emissions.

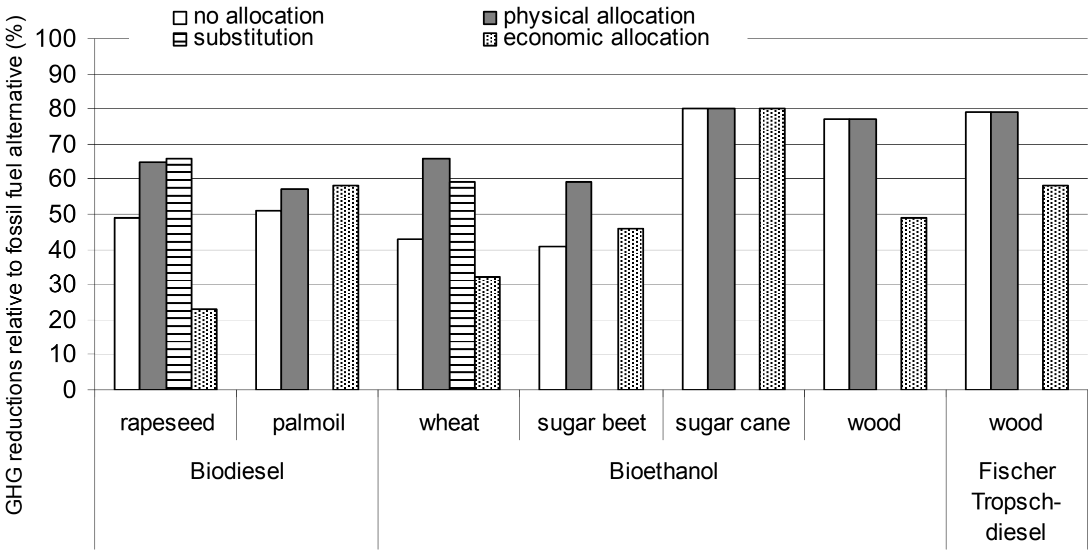

Figure 6.6. Prevented GHG emissions per conversion route for different allocation methods and different sources. No allocation, substitution and physical allocation are based on Eickhout et al., 2008. Economic allocation is taken from Hamelinck and Hoogwijk, 2007.

In the above figure, indirect land use changes are not considered and resulting GHG emissions are not taken into account. This aspect will reduce the gains in GHG emissions in the short term. Only when current arable land is converted into perennial crops for 2nd generation biofuels this effects might be reversed in the long run. The effects of these indirect effects are so over-riding that GHG balances will become negative. Therefore, the current debate is focused on how direct and indirect land-use change impacts can be included in the GHG calculations. This aspect of indirect effects will remain of importance the coming years.

Consequences for development

The current debate on development focuses on the impact of biofuels for the food price. According to one IFPRI study, the contribution of biofuel demand to increases in grain prices from 2000 to 2007 is about 30% (Rosegrant 2008). That is: recent biofuel expansion may be an important determinant of rising food prices in the short-term, it does not appear to have been an overwhelming force. But this may change in the future as expansion rates accelerate – in response to policy initiatives, or otherwise. Other studies suggest smaller (FAO) or larger price effects (World Bank 2008).

In the future, mandatory mixing of biofuels are expected to lead to increases in the price of crops that may be used as an input in biofuel production, and possibly in the price of all food commodities. Several agro-economic models seem to agree on this, despite different modelling approaches (Chapter 5). However, the larger uncertainty lies in the potential impact for development. Changing food prices may affect the “rich” and the “poor” differently. Specifically, even modest price increase can have adverse effects on food security for the poor in developing countries, who are exposed to greater risks in terms of food prices than the rich. Therefore, the OECD concludes that “the higher prices for basic food commodities represents a substantial threat to low-income consumers in developing countries”. However, higher food prices also represent additional income opportunities for some of the world’s (rural) poor. Therefore, a distinction should be made between net exporters and net importers of food (at the national as well as the household level). Moreover, the development prospects are partly determined by the scale at which production of energy crops will take place (plantation-style or accommodation within existing farming styles). Not much research is done at this topic, so far.

Future oil price

Most of the agro-economic studies (with the exception of general equilibrium analyses like LEITAP) use exogenous assumptions on the price of oil. Higher energy prices trigger additional usage of agricultural products as fuel in baseline results. Therefore, the oil price is very important for the output of agro-economic models (Chapter 5).

Additionally, the simulations of additional costs of a 10% biofuels target for 2020 are also very dependent of future fossil fuel prices (Chapter 4). Furthermore, biofuel prices will respond to oil prices as fossil energy is an essential input in the biofuel production chain. These results are also dependent of the assumption on the share of second generation biofuels, which are also highly uncertain as explained above.

Uncertainty margins assessed

These uncertainties have been translated into plausible ranges for calculating the requirements for land, reductions in GHG emissions and replacement of food production. For the calculations we have assumed the following,

- 1, 5, 10 or 30% of the global transport fuels are supplied by biofuels;
- zero (scenario 1) or 40% (scenario2) of the biofuels is produced from 2nd generation crops;
- 50% of the feedstock for 2nd generation biofuels is derived from residues (scenario 3);
- for the production of the energy crops in the world, either food crops or non-food crops, average yield levels in 2020 have been assumed or production levels on current highest production areas were chosen;
- the composition of the energy crops by 2020 is based on our expert judgment;
- the percentage GHG emission reduction of biofuel chains in 2020 is either 60% (low) or 80% (high) relative to the emission of the replaced fossil fuel and
- 20, 50 or 80% of total land claim for biofuels is derived from natural lands.

The results of the calculations have been presented only to indicate the range in claims (Table 6.2). E.g., at a 10% blending target substantial amounts of land claims are projected on which it is possible to produce an EU-like diet for large numbers of people (several millions to several hundred millions, depending on the region) with only a moderately low level of direct GHG emission reduction relative to the emission in 2005. Further details and parameter values can be found in Annex 1.

Table 6.2. Calculated impacts of blending targets for the Netherlands (NL), the European Union (EU27) and the world on land claims for biofuels production, amount of people that can be fed at this acreage with an EU-like diet and the direct GHG emission reduction in the biofuel chain (further details in Annex 1).

Blending target	Region	Land claim (10^6 ha)			Food production (10^6 people)			Direct GHG emission reduction	
		Scenario			Scenario			(as % of GHG emission in 2005)	
		1	2	3	1	2	3	Low	High
1%	NL	0.081	0.074	0.061	0.36	0.32	0.27	0.1%	0.2%
	EU27	2.1	1.9	1.6	9.3	8.5	7.0	0.1%	0.2%
	World_a	17.6	14.8	12.7	45.7	36.9	31.7	0.1%	0.1%
	World_b	10.7	10.6	8.5	45.7	36.9	31.7	0.1%	0.1%
5%	NL	0.405	0.369	0.306	1.8	1.6	1.3	0.7%	0.9%
	EU27	10.6	9.6	8.0	46.5	42.4	35.1	0.7%	1.0%
	World_a	88.1	73.8	63.3	228	184	158	0.5%	0.6%
	World_b	53.4	53.0	42.5	228	184	158	0.5%	0.6%
10%	NL	0.810	0.738	0.612	3.6	3.2	2.7	1.3%	1.8%
	EU27	21.2	19.3	16.0	93	85	70	1.4%	1.9%
	World_a	176	148	127	457	369	317	0.9%	1.2%
	World_b	107	106	85	457	369	317	0.9%	1.2%
30%	NL	2.4	2.2	1.8	10.7	9.7	8.1	4.0%	5.4%
	EU27	63.6	57.9	48.0	279	254	211	4.3%	5.7%
	World_a	529	443	380	1371	1107	950	2.8%	3.7%
	World_b	321	318	255	1371	1107	950	2.8%	3.7%

Note: World_a refers to average yield levels, world_b to yield levels from current highest production areas.

Results on the total (direct + indirect) GHG emission reduction is given in Table 6.3. Indirect emissions depend on the amount of natural lands converted into arable land. Therefore a number of levels has been chosen to illustrate the impact of the land use change. Relative reduction values below 0.3 are not allowed for biofuel chains according to current policies and values below zero increase rather than decrease the GHG emission. The results show that given the assumptions in Annex 1, none of the calculated GHG balances under land use change (starting from 20% of total land claim) is meeting the proposed standard of the EC on biofuel chains.

Table 6.3. Estimated impacts of the share of indirect land use on the total GHG emission reduction in 2020 (expressed as fraction of the avoided CO_2 emission from replaced fossil fuels). The share of indirect land use is taken relative to the total land claim for biofuels (see Table above).

Region	Share of land use change	Total GHG emission reduction (relative to fossil fuel reference chain)						
		0	0.2		0.5		0.8	
	Scenario	All	1	3	1	3	1	3
NL		0.7	0.07	0.22	-0.88	-0.50	-1.83	-1.21
World_a		0.7	-0.16	0.08	-1.45	-0.84	-2.74	-1.77
World_b		0.7	0.18	0.29	-0.60	-0.34	-1.38	-0.96

Note: minimum proposed ratios for biofuel chains range from 0.3 (European Commission) to 0.6 in 2020 (European Parliament).

7.3 Robust conclusions

Above we have outlined the main uncertainties in relation to the availability of sustainable biofuels in 2020 and its implications for sustainability components. Based on the underlying chapters that have looked into the expected near future developments in the biofuel sector we draw some robust conclusions for the timeframe 2020 on implications of obligatory blending target.

- **The biofuels target will increase the demand for land for agriculture**

While some of this additional claim could be met by intensifying agricultural production, expansion of agricultural area is expected for 2020. Both options will inherently cause additional claims for water, nutrients, and biocides.

- **The biofuels target will affect biodiversity negatively**

Both intensification and expansion of land will have an overall negative effect on biodiversity.

- **The biofuels target will increase food prices**

The obligatory blending target is a price inelastic incentive that cause increases in food prices under competition.

- **The biofuels target will increase transport fuel prices and add costs to society**

Within the timeframe considered it is not expected that costs of biofuels are below production costs of fossil fuels and therefore additional costs are expected. These calculations do not even include additional costs for infrastructure.

- **The biofuels target can avoid direct GHG emissions**

Provided good management of the energy crop, savings can be expected from most biofuel conversion routes.

- **The biofuels target can increase total GHG emissions due to direct or indirect land use change**

If carbon rich ecosystems are cleared, either directly or indirectly, land use changes will offset the direct GHG emissions reductions.

- **The biofuels target does not lead to a least cost GHG mitigation trajectory.**

Biofuels is an expensive technology and in terms of GHG emissions reduction other alternatives are available at lower costs.

- **There are hardly any non-fossil fuel alternatives other than biofuels for heavy transport and aviation**

For the medium to longer term there is no suitable alternative for kerosene and diesel for aviation and the long-distance road transport. Assuming current transport technologies this implies there will remain a long-term market for biofuels, particularly middle distillates.

7.4 Two Perspectives

In what follows, we present two possible perspectives on the impacts of Dutch mandatory mixing policies in 2020 on various sustainability criteria. First, however, a caveat is in order. The total amount of biofuels to meet the blending targets of the Netherlands are so small relative to the European and global demands that the Netherlands should be regarded as a “price taker.” Dutch going-alone policy initiatives will not significantly affect European biofuels production, even at targets of 20%, and will have negligible effects on global food or energy prices, i.e. it will have a negligible effect on global poverty and food security statistics, though making its proportional contribution. Of course, the situation is different for EU-wide policies. In that case the “robust conclusions” outlined above are relevant.

Perspective 1

The estimated land area required for a 10% obligatory blending target for biofuels for the Netherlands transport sector ranges from 610 to 810 thousand hectares. These are substantial areas as compared to the acreage of current intensively used arable land of some 900 thousand hectares. On these lands tied up for biofuel production, enough food could be grown to feed 2.7 to 3.6 million people with a diet currently consumed in the EU. Doubling the blending target to 20% implies twice as large a claim on land.

It is inevitable that the Netherlands will have to import its feedstock for biofuels, putting a claim on land and other resources outside its territories. Given the 2020 time span, it is unlikely that policy measures can be implemented to prevent all indirect effects. These effects can only be prevented when agricultural productivity worldwide would be raised to levels that the required 85 to 180 million hectares of current agricultural lands are alleviated for the production of feedstock in order to produce biofuels at a 10% global blending target for transport energy. This is, however, not realistic for the near term, because the global amount of agricultural land should already increase to meet the estimated demand for food and feed. It is further unlikely that all conditions will be in place by 2020 to boost yield improvements to levels that would alleviate agricultural lands. Part, if not all, of the lands required for biofuels production will follow from direct or indirect conversion of “unused” land, including (semi-) natural lands like forests, to agricultural fields.

The use of marginal lands will only play a marginal role by 2020 because of the slow ecological processes to improve the lands and the associated high investments of bringing these lands to an economically viable production level. As mentioned above, a Dutch blending policy is unlikely to have an impact on (global) food markets, though it does contribute to the total claims on food.

Does a mandatory blending target policy contribute to attenuating the risk of global warming? One may argue it does not. Assuming good management in 2020 and therefore 60-80% efficiency in GHG replacement of biofuels relative to fossil fuels, the 10% mixing rule prevents total emissions of 3 to 4 million tons CO_2-equivalents; on average 1.6% of total CO_2-equivalent emission in the Netherlands in 2005. However, these “gross gains” are reduced to zero when one quarter to one third of the required land would be obtained from natural lands, and turn negative at higher land clearing, which is most likely.

Are the blending targets favourable for the resource base and the environment? This is not likely to be true. In recent years, the resource base for agricultural production, notably water availability and soil fertility, has been under increasing pressure, leading to a decline in overall availability per person and adverse effects to the environment. Measures to combat these problems have been identified, but implementation appears to be a complex time consuming agro-technical, institutional and economic undertaking. As the demand is growing faster than a sustainable supply can provide in the near term, blending targets for biofuels are likely to further deteriorate the resource base, including the loss of biodiversity. Moreover, the necessary intensification of biomass production will also lead to higher emissions of pollutants to the environment or withdrawals of resources from natural systems.

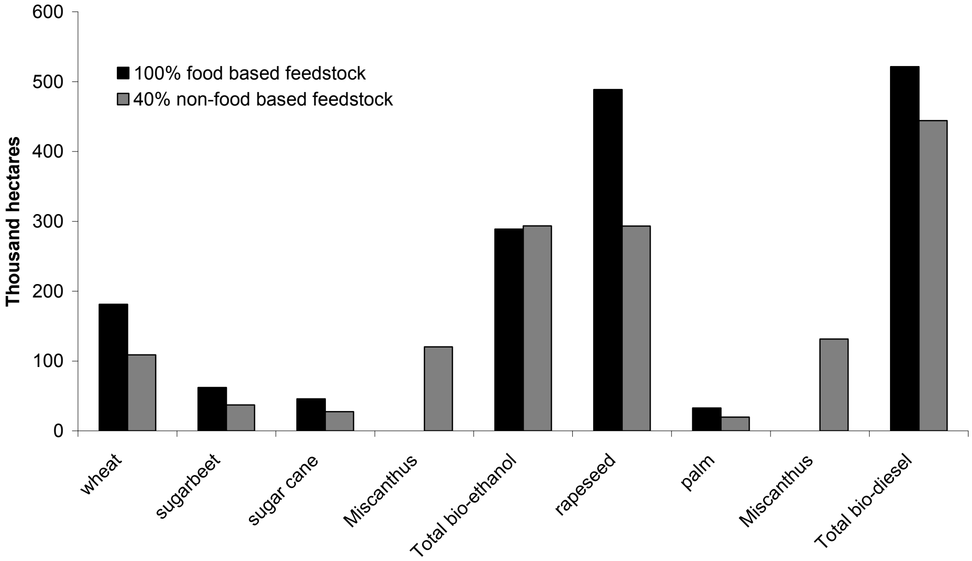

Figure 6.7. The total acreage needed to meet a blending target of 10% by the Netherlands (see Annex 1 for assumptions).

Assuming that the blending targets contribute to GHG reductions, is it a cost-effective option? It is not. The OECD estimates that the total costs are in the range of 960-1700 US$ per tons of CO_2 saved, though costs may be lower when considering all effects evolving from a biofuels policy, including savings, or might be infinite when GHG reductions would be zero or less when indirect effects would also be accounted for. In light of alternative means of GHG savings ranging from 7-22 US$ per ton, mandatory blending appears to be an overly expensive way to fight climate change. This implies that mandatory blending policies appear an unwise policy alternative for this goal. A going alone policy will not promote (agricultural) development elsewhere, and does not contribute to mitigating the emissions of GHG—the reverse may be true.

The situation does not improve when “scaling up” to EU-wide policies. In that case, the claim on land increases roughly by a factor of 26, and the potentially adverse impacts on the GHG balance are accentuated, especially if forests are converted for agricultural lands. In addition, EU-wide policies are likely to exert an upward effect on global food markets. This offers opportunities for agricultural producers in the EU and elsewhere, but in the short term will contribute to poverty and divert the global system away from achieving the MDGs. Prices will go up and for poor people, e.g. spending 50% or more of their income to food, this will have negative effects on their poverty situation and food security. Development may be stimulated by an increased trade in biomass but it is highly questionable who will benefit most. For African countries for instance, who are net importers of food, it is possible that the demand for fuel crops will be satisfied by large scale fuel crop plantations that achieve little in terms of participatory and inclusive growth.

In short, even when accounting for un-securities in future developments, biofuels blending policy for the near term of 2020 will lead to a most probable outcome that poverty, food security, global GHG balance, biodiversity and competition for natural resources are worsened rather than improved.

Perspective 2

Biofuels are generally advocated as one of the very few short-term options for the challenges the transport sector is facing in terms of reducing its greenhouse gases and reducing its dependency of fossil oil. Particularly when major efforts are required in the short term, biofuels will need to play an important role.

However, as this assessment has also shown, biofuels come with several risks: for additional claims on agricultural land, also leading to greenhouse gas emissions due to land use change, for poor greenhouse gas emission reductions through the biofuels production chain, for reduced food security and for increasing poverty. The crucial assumption in this perspective is that the new involvement of the energy and transport sector in agriculture and land use will fundamentally change the way these develop. In a response to the risks mentioned, many national governments that stimulate biofuels or plan to do so are currently developing mechanisms or supporting policies to spur biofuels development in a responsible manner. Efforts are made in several domains: sustainability certification of biofuels, additional investments in agricultural improvement, and the development of (2nd generation) biofuels that use agricultural and forestry residues as their primary feedstock. Central assumption in this perspective is that these, often internationally coordinated efforts will be successful in inducing a development pathway of biofuels without major negative impacts.

Additional claims on land

As specified in the uncertainties, demand for agricultural feedstock due to biofuels can be met by basically two developments: Additional improvements in agricultural yields and bringing new land into production. In terms of biophysical potential, many regions of the world show opportunities to dramatically increase their agricultural production, thereby meeting the lion's share of additional demand by yield increases on existing productive lands. Examples of this are the EU new member states and the members of the former Soviet Union, in which production has collapsed after the beginning of the 90s. Here, new demand for biofuels may be a key trigger for an agricultural revival, after a long period in which prices for agricultural commodities structurally decreased over time. Furthermore, as shown in the illustrative calculations, a strong introduction of residues-fed 2nd generation biofuels can significantly reduce demand for agricultural commodities, thereby reducing the challenges to agriculture.

However, some additional claims on land will probably occur. Then the central question will be what types of land will be converted. Again, the public attention for biofuels can be an additional trigger for putting e.g. deforestation prevention on the agenda. Mechanisms for taking lands into production with less high carbon and biodiversity stocks may be developed, thereby reducing the negative impacts of land use change. This, however, is a complex issue about which international developments are still in their infant stage.

GHG emissions of the biofuels production chain

Poor agricultural and chain management can lead to substantially lower greenhouse gas emission reductions compared to the ones given for proper management. However, all certification efforts that are currently being developed, both the ones at governmental level and the ones developed by private parties, set standards to minimum GHG reductions. It can be expected that these systems will be operational before 2020, thereby sufficiently safeguarding GHG performance of the biofuels chain.

GHG emissions due to indirect land use change

The GHG impacts of indirect land use change directly relate to the issues discussed in the additional claims on land. Again, provided that international biofuel-induced developments lead to further productivity increases, strong development of 2nd generation, and sensible land use change, GHG impacts of indirect land use change may be reduced to such levels that overall greenhouse gas emission reductions remain significantly positive.

Impacts on food security

The relation between biofuels and food security will be a critical one as long as biofuels use agricultural land for their feedstock production. This also means that the efforts mentioned earlier in this perspective can strongly reduce the threat of biofuels to food security. Again, if biofuels function as an incentive for structurally and significantly improving agricultural productivities, their impact on food security could even be positive.

Impacts on poverty and opportunities for development

One of the probable consequences of biofuels is a rise in commodity prices. This is also an essential mechanism to spur agricultural productivities. On poverty and development, impacts will differ greatly between net food producers and food consumers. Farmers in all regions of the world may profit, while especially the urban poor are vulnerable for price increases. At least partly, this is therefore a distributional problem. In line with this issue, voices are raised to monitor these impacts, with the view that biofuels targets can be changed during a feedstock supply crunch. For example, this options under discussion in the EU RES directive preparations. If this leads to mechanisms of adequate and rapid response, this can serve as a safety valve for too negative impacts of biofuels.

Closing remarks perspective 2

According to this perspective, biofuels will be a necessary and sustainable new option for the energy sector. However, it depends on some critical developments in the EU and global development of biofuels policies, namely that additional to a biofuels target:

- Parallel policies, e.g. on EU level, induce a significant and sustainable additional improvement in agricultural yields worldwide;
- Parallel policies induce a rapid introduction of 2nd generation biofuels, mainly based on (agricultural and forest-based) residues;
- Parallel policies lead to conversion of lands with low carbon and biodiversity stocks;
- Sustainability certification mechanisms provide sufficient guarantee for good agricultural management and corresponding substantial greenhouse gas emission reductions on chain level;
- Biofuel policies, specifically when they aim at biofuels that use land, are made responsive to food supply crunches.

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Annex I Background data

In this annex the background data are given that were used in the calculations for the synthesis (Tables 6.2 and 6.3).

Table A.1. Primary energy use in the road transport sector as projected for 2020.

Region	Mtoe y^{-1}	EJ y^{-1}(a)	Source
NL	13.4	0.560	1
EU-27	350	14.6	2
World	2150	90	3

(a) according to the proposed EC directive 10% of the primary use in the EU should be provided by the net energy (content) of biofuels (see table A.2)

Table A.2. Used characteristics of fuels.

Fuel type	Energy content (MJ l^{-1})	CO_2 emission (kg CO_2 GJ^{-1})	Source
Gasoline		83.8	4
Diesel		83.8	4
Ethanol	21.2		
Bio-diesel	32.5		
FT-diesel	34.5		

Table A.3. Scenarios of feedstock use for biofuels where each feedstock produces a share of the total volume of ethanol (1-6) or biodiesel (7-11).

Region	EU and NL			World		
Scenario	1	2	3	1	2	3
Feedstock						
1. Wheat	0.4	0.24	0.24	0.2	0.12	0.12
2. Sugar beet	0.3	0.18	018	0.2	0.11	0.11
3. Sugar cane	0.3	0.18	0.18	0.4	0.24	0.24
4. Maize	0	0	0	0.2	0.12	0.12
5. Wood-ethanol	0	0.4	0.2	0	0.4	0.2
6. Residues-ethanol	0	0	0.2	0	0	0.2
7. Rapeseed	0.8	0.48	0.48	0.7	0.42	0.42
8. Oil palm	0.2	0.12	0.12	0.2	0.12	0.12
9. Soy beans	0	0	0	0.1	0.06	0.06
10. Wood-FT-diesel	0	0.4	0.2	0	0.4	0.2
11. Residues-FT-diesel	0	0	0.2	0	0	0.2

Note: it has been assumed that for NL and EU ethanol will replace 45% of the target in energy, leaving 55% for bio-diesel which is comparable to the relative use of both fuels in the EU (5). For the world the assumed distribution is 80% (ethanol) and 20% (biodiesel), according to the projected relative use from the OECD-FAO Outlook in 2017 (6).

Table A.4. Estimated average biofuel yield of the feedstocks in 2020 (l biofuel ha^{-1} y^{-1}) and the region in which the feedstock is grown (11).

Region	EU and NL		World			
Feedstock	Yield	Region	Yield	Region	Yield	Region
1. Wheat	2624	Europe	1352	World	2624	Europe
2. Sugar beet	5753	Europe	4634	World	5753	Europe
3. Sugar cane	7802	Latin America	5921	World	7802	Latin America
4. Maize	-		2261	World	4602	North America
5. Wood-ethanol	3956	World	3956	World	3956	World
7. Rapeseed	1551	Europe	875	World	1551	Europe
8. Oil palm	5797	Asia	3841	World	5797	Asia
9. Soy beans	-		476	World	531	Latin America
10.Wood-FT-diesel	2716	World	2716	World	2716	World

Note: For the EU and NL only one set of yield data has been used in the calculations, whereas for the world two sets have been applied with feedstock growing in different parts of the world leading to different estimates of yields (in general low and high values, except for wood).

Other assumptions

- The same distance can be driven with 1 MJ of biofuel and 1 MJ of fossil fuel.
- An average EU diet needs an equivalent of 3.5 kg of wheat grain dry matter per person per day (8).
- The wheat yields corresponding to Table A.4 are 6.6 (Europe) and 3.4 (World) ton fresh grain yield ha^{-1} per year with an assumed dry matter content of 85%.
- In tropical areas where sugar cane and oil palm are grown, two wheat crop cycles can be grown.
- The percentage direct GHG emission reduction of biofuel chains in 2020 is between 60 and 80% relative to the emission of the replaced fossil fuel (this report).
- Conversion of natural lands into arable lands creates an extra emission of 18.3 t CO_2 ha^{-1} per year (based on a difference in carbon storage of 100 t ha^{-1} and a period of 20 years, see also 9).
- The total emission of CO_2-eq. in 2005 amounts 210 Mt in the Netherlands (10), 5.2 Gt in EU-27 (11) and 49 Gt in the world (12).

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