Towards sustainable production
and use of resources:

ASSESSING BIOFUELS

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Preface

Biofuels have attracted growing attention of policy, industry and research. The number of scientific publications devoted to biofuels is growing exponentially, and the number of reviews is increasing rapidly. For decision makers it has become a hard job to find robust reference material and solid guidance. Uncertainty on the overall assessment has been growing with the findings of the possible benefits and risks of biofuels.

The International Panel for Sustainable Resource Management is taking up the challenge and, as its first report, provides another review on the widely debated field. It does so in the conviction that substantial progress requires an advanced approach which goes beyond the production and use of biofuels, and considers all competing applications of biomass, including food, fibres and fuels. A widened systems perspective is adopted with a particular focus on the potential impacts of land use change depending on the types of biofuels used and growth of demand.

This report is the result of a thorough review process, based on research of recent publications (mainly until the end of 2008, but considering also eminent articles published before June 2009), and the involvement of many experts worldwide. In particular, the report benefitted substantially from the exchange with the Rapid Assessment workshop held by the International SCOPE biofuels project in Germany, September 2008, and the subsequent publication of the proceedings, which had involved about 75 scientists from all continents and reflected a broad range of different views concerning the analysis and assessment of biofuels.

The preparation of this report has been guided by the Biofuels Working Group of the Resource Panel. A Zero Draft was prepared for discussion at the Santa Barbara meeting, November 2008. Based on the discussions and subsequent comments in the panel and the Steering Committee, the text was further developed by the team of authors towards a First Draft. This was provided to the Panel in March 2009 asking for approval to enter the review process. The comments of four reviewers were provided to the authors by the Peer Review coordinator in April and were taken as a basis for revision towards the Second Draft. The Second Draft was discussed and approved by the Resource Panel and the Steering Committee in Paris, June 2009, and finalised for publication taking into account last comments by the Steering Committee and involved experts.

The report intends to provide policy relevant information on the assessment of the environmental and social costs and benefits of biofuels. It examines both the concerns of critical developments, and describes the options for a more sustainable use of biomass and measures to increase resource productivity.
The focus is on first generation biofuels thus reflecting the state-of-the-art and data reliability.
Nevertheless, the report puts technology and policy development into perspective. It marks uncertainties and addresses the needs for research and development, also for advanced biofuels. In doing so,
it delivers no final word, but a concentration of current knowledge, aimed to support decision making and future scientific work towards a sustainable "bio-economy".

Prof. Ernst U. von Weizsäcker
Co-Chair of the International Panel
for Sustainable Resource Management

Dr. Stefan Bringezu
Chair of the Biofuels Working Group

Preface

Biofuels are a subject that has triggered sharply polarized views among policy-makers and the public. They are characterized by some as a panacea representing a central technology in the fight against climate change. Others criticise them as a diversion from the tough climate mitigation actions needed or a threat to food security and thus a key challenge to the achievement of the poverty-related Millennium Development Goals.

This first report by the International Panel for Sustainable Resource Management, which is based on the best available science, brings a life-cycle approach to the issue. It makes clear that wider and interrelated factors needed to be considered when deciding on the relative merits of pursuing one biofuel over another.

What are the likely contributions to climate change from different crops and what are the impacts on agriculture and croplands up to freshwaters and biodiversity from the various options available?

The report also underlines the role of biofuels within the wider climate change agenda including options to reduce greenhouse gas emissions from the transportation sector by means other than biofuels – fuel efficiency standards for vehicles and the development of hybrids and electric cars are a case in point.

Meanwhile the assessment outlines options for energy generation from biomass at dedicated power plants and combined heat and power stations as an alternative approach to converting crops or crop wastes into liquid fuels.

Above all the report spotlights the complexity of the subject and indicates that simplistic approaches are unlikely to deliver a sustainable biofuels industry nor one that can contribute to the climate change challenge and the improvement of farmers' livelihoods.

While this assessment is not prescriptive, its empirical and scientific analysis of different biofuel options provides a number of clear reference points for the future development of the sector.

Clearing tropical forests for biodiesel production, and in particular those on peatlands leads to far greater carbon emissions than those saved by substituting biofuel for fossil fuel in vehicles.

The panel, chaired by Professor Ernst von Weizsäcker, has focused on the current generation of biofuels and only partially looks to the future. Researchers are already studying advanced biofuels from sources such as algae or the natural enzymes used by termites to dissolve wood into sugars. These second or third generation technologies will require their own life cycle assessments.

I believe that this assessment of contemporary biofuels and the options it outlines will make an important contribution to the policy-debate and policy-options governments may wish to pursue.

It has sought to answer a number of key questions on biofuels while pointing to additional assessment and research priorities which need to be now addressed.

Achim Steiner
UN Under-Secretary General and
Executive Director, UN Environment Programme (UNEP)

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Abbreviations and acronyms

BIG/CC	biomass integration gasification using combined cycle
BtL	biomass to liquid
CHP	combined heat and power
CSP	concentrating solar thermal power
DDGS	dried distillers grains with solubles
EC	European Commission
EU-25	European Union with 25 Member States
EU-27	European Union with 27 Member States (i.e. EU25 plus Bulgaria and Romania; since 2007)
EurepGAP	Euro-Retailer Produce Working Group Good Agricultural Practices
FAO	Food and Agriculture Organisation of the United Nations
FT	Fischer-Tropsch
GBEP	Global Bioenergy Partnership
GEDnet	Global Type III Environmental Product Declarations Network
GEF	Global Environment Facility
GFEC	global final energy consumption
GHG	greenhouse gas
GMO	genetically modified organism
GWP	global warming potential
HIC	high income countries
IEA	International Energy Agency
IFEU	Institute for Energy and Environmental Research
IFPRI	International Food Policy Research Institute
IPCC	Inter-governmental Panel on Climate Change
IRGC	International Risk Governance Council
ISO	International Standard Organisation
LCA	life cycle assessment
LIC	low income countries
MIC	middle income countries
MSW	municipal solid waste
OECD	Organisation for Economic Co-operation and Development
PV	photovoltaic
RFA	Renewable Fuels Agency
RSB	Roundtable on Sustainable Biofuels
SCOPE	Scientific Committee on Problems of the Environment
SRF	short rotation forestry
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation

Units

a	year
CO_2eq	carbon dioxide equivalents
EJ	exajoule (10^{18} joules)
Gt	gigatonne (10^9 tonnes)
GW	gigawatt (10^9 watts)
GWh	gigawatt hour
GWth	Gigawatt thermal
ha	hectare
kcal	kilocalorie
kg	kilogram (10^3 grams)
kW	kilowatt (10^3 watts)
kWh	kilowatt hour
kWth	kilowatt thermal
m^2	square meters
Mg	megagram (10^6 grams)
Mha	million hectares
MJ	megajoule (10^6 joules)
Mt	megatonne (10^6 tonnes)
Mtoe	million tonnes of oil equivalent
MW	megawatt (10^6 watts)
MWe	megawatt electrical
MWth	megawatt thermal
p.a.	per annum
PJ	petajoule (10^{15} joules)
t	tonne
TW	terawatt (10^{12} watts)
TWh	terawatt hour
W	watt

Chemical abbreviations

CH_4	methane
CO_2	carbon dioxide
DME	dimethyl ether
DMF	dimethylfuran
ETBE	ethyl-tertiary-butyl-ether
EtOH	ethanol
FAME	fatty acid methyl ester
H_2	hydrogen
MeOH	methanol
N	nitrogen
N_2O	nitrous oxide
NO_x	nitrogen oxide
P	phosphorous
RME	rape methyl ester

Summary

Objective and scope

This report provides an overview of the key problems and perspectives toward sustainable production and use of biofuels. It is based on an extensive literature study, taking into account recent major reviews, and considering a wide range of different views from eminent experts worldwide. The focus is on so-called first generation biofuels while considering further lines of development. This focus is due to state-of-the-art and data availability until the end of 2008. Potential benefits and impacts of second and third generation biofuels – preferably referred to as 'advanced biofuels' – are partially included, and might be subject to a specific report at a later stage.

The report focusses on the global situation, recognising regional differences.

In the overall context of enhancing resource productivity, options for more efficient and sustainable production and use of biomass are examined. In particular, "modern biomass use" for energetic purposes, such as biomass used for (co-)generation of heat and power and liquid biofuels for transport, are addressed and related to the use of biomass for food and material purposes. Whereas improving the efficiency of biomass production plays a certain role towards enhancing sustainability, progress will ultimately depend on a more efficient use of biotic (and abiotic) resources (incl. for instance, an increased fuel economy of car fleets), although a full consideration of all relevant strategies towards this end (e.g. changing diets high in animal based foods and reducing food losses) is beyond the scope of this report.

Important trends and drivers

Current and projected use and potentials of biofuels

In developing countries, over 500 million households still use traditional biomass for cooking and heating. But already 25 million households cook and light their homes with biogas and a growing number of small industries, including agricultural processing, obtain process heat and motive power from small-scale biogas digesters.

Biomass contributed about 1% to the total global electric power capacity of 4,300 GW in 2006. It is to a growing extent employed for combined heating and power (CHP), with recent increases in European countries and developing countries like Brazil.

Many countries have set policy targets for renewable energy, but only a few specify the role of biomass.

World ethanol production for transport fuel tripled between 2000 and 2007 from 17 billion to more than 52 billion litres, while biodiesel expanded eleven-fold from less than 1 billion to almost 11 billion litres. Altogether biofuels provided 1.8% of the world's transport fuel. Recent estimates indicate a continued high growth. From 2007 to 2008, the share of ethanol in global gasoline type fuel use was estimated to increase from 3.78% to 5.46%, and the share of biodiesel in global diesel type fuel use from 0.93% to 1.5%.

The main producing countries for transport biofuels are the USA, Brazil, and the EU. Production in the United States consists mostly of ethanol from corn, in Brazil of ethanol from sugar cane, and in the European Union mostly of biodiesel from rapeseed. Other countries producing fuel ethanol include Australia, Canada, China, Colombia, the Dominican Republic, France, Germany, India, Jamaica, Malawi, Poland, South Africa, Spain, Sweden, Thailand, and Zambia. Rapid expansion of biodiesel production occurred in Southeast Asia (Malaysia, Indonesia, Singapore and China), Latin America (Argentina and Brazil), and Southeast Europe (Romania and Serbia).

Investment into biofuels production capacity probably exceeded $4 billion worldwide in 2007 and seems to be growing rapidly. Industry with government support also invests heavily in the development of advanced biofuels.

International trade in ethanol and biodiesel has been small so far (about 3 billion litres per year over 2006/07), but is expected to grow rapidly in countries like Brazil, which reached a record-high of about 5 billion litres of ethanol fuel export in 2008.

Policies have essentially triggered the development of biofuel demand by targets and blending quotas. Mandates for blending biofuels into vehicle fuels had been enacted in at least 36 states/provinces and 17 countries at the national level by 2006. Most mandates require blending 10–15% ethanol with gasoline or blending 2–5% biodiesel with diesel fuel. In addition, recent targets define higher levels of envisaged biofuel use in various countries.

Regarding the global long-term bioenergy potential, estimates depend critically on assumptions, particularly on the availability of agricultural land for non-food production. Whereas more optimistic assumptions lead to a theoretical potential of 200-400 EJ/a or even higher, the most pessimistic scenario relies only on the use of organic waste and residues, providing a minimum of 40 EJ/a. More realistic assessments considering environmental constraints estimate a sustainable potential of 40 – 85 EJ/a by 2050. For comparison, current fossil energy use totals 388 EJ.

In the short to medium term, projections expect biomass and waste to contribute 56 EJ/a in 2015 and 68 EJ/a in 2030. Global use of bioethanol and biodiesel will nearly double from 2005-2007 to 2017. Most of this increase will probably be due to biofuel use in the USA, the EU, Brazil and China. But other countries could also develop towards significant biofuel consumption, such as Indonesia, Australia, Canada, Thailand and the Philippines.

Development of agricultural yields

Future development of global agricultural yields will determine the degree to which demand for food and non-food biomass can be supplied from existing cultivated land. Commodity prices are very likely to be significantly influenced by future yield developments. Although the overall development seems rather uncertain, various influences (such as water supply, climate change, environmental restrictions, the evolution of agricultural markets) make it rather unlikely that the growth rates of past decades will continue globally. A declining tendency in the yearly percentage of yield increases of major crops has been observed over the past decades.

A higher potential for yield improvements is commonly seen for developing countries, and often especially for Africa. However, the FAO assumes future yield increases for cereals in developing countries which are closer to lower global average rates of recent years, i.e. around 1% per year. Plausible estimates from international institutions for global yields in the next decade are 1-1.1% p.a. for cereals, 1.3% p.a. for wheat and coarse grains, 1.3% p.a. for roots and tubers and 1.7% p.a. for oilseeds and vegetable oils. These rates of increase are significantly below average rates of the past four decades.

Recent findings show that climate change has already reduced average crop yields. Future development may widen the gap between developed and developing countries, by decreasing production capacity in particular in semi-arid regions and increasing capacity in temperate zones. A higher frequency of extreme weather events will further increase uncertainty.

Development of food demand

In the past, agricultural yields grew faster than the world population. More food could be produced on existing cropland. In the future, the trends might become less favourable, as average crop yields may compensate for population growth but not for an increasing demand of animal based food. Between 2000 and 2030 the global population is expected to grow by 36% (medium projection of UN/FAO). This would be about the same rate that average crop yields are expected to increase. At the same time, however, food demand is changing towards a higher share of animal based diets, particularly in developing countries. The FAO expects the meat consumption of the world population to increase by ca. 22% per capita from 2000 to 2030, the milk & dairy consumption by 11% and that of vegetable oils by 45%. Commodities with lower land requirements like cereals, roots and tubers, and pulses will increase at lower rates per capita.

As yield increases will probably not compensate for the growing and changing food demand, cropland will have to be expanded only to feed the world population. So far no explicit projection of global land use change induced by changing food demand seems to be available. From the Gallagher report [1], an estimated additional requirement of 144 to 334 Mha of global cropland for food in 2020 can be derived.

Any further requirements, for instance for fuel crops, will be added on top of this.

Life-cycle-wide environmental impacts of biofuels

The green house gas balances of biofuels

Life-cycle-assessments (LCA) of biofuels show a wide range of net greenhouse gas savings compared to fossil fuels. This mainly depends on the feedstock and conversion technology, but also on other factors, including methodological assumptions (see Fig. 4.3). For ethanol, the highest GHG savings are recorded for sugar cane (70% to more than 100%), whereas corn can save up to 60% but may also cause 5% more GHG emissions. The highest variations are observed for biodiesel from palm oil and soya. High savings of the former depend on high yields, those of the latter on credits of by-products. Negative GHG savings, i.e. increased emissions, may result in particular when production takes place on converted natural land and the associated mobilisation of carbon stocks is accounted for. High GHG savings are recorded from biogas derived from manure and ethanol derived from agricultural and forest residues, as well as for biodiesel from wood (BtL, based on experimental plants).

Impacts insufficiently covered by available LCA

Besides GHG emissions, other impacts such as eutrophication and acidification need to be considered. The available knowledge from life-cycle-assessments, however, seems limited, despite the fact that for those issues many biofuels cause higher environmental pressures than fossil fuels. From a representative sample of LCA studies on biofuels, less than one third presented results for acidification and eutrophication, and only a few for toxicity potential (either human toxicity or eco-toxicity, or both), summer smog, ozone depletion or abiotic resource depletion potential, and none on biodiversity. Increased eutrophication is a key characteristic of biofuels from energy crops when compared with fossil fuels. The life-cycle-wide emissions of nutrients depend critically on the application and losses of fertilisers during the agricultural production of biofuel feedstocks.

There is an obvious link between environmental impacts estimated by life-cycle impact assessments and water quality problems described at the regional scale. For instance, in the Mississippi drainage basin, increased corn acreage and fertiliser application rates, due to growing biofuel production, have been shown to increase nitrogen and phosphorus losses to streams, rivers, lakes and coastal waters, particularly in the Northern Gulf of Mexico and Atlantic coastal waters downstream of expanding production areas, leading to serious hypoxia problems. These observations indicate that besides GHG emissions, other impacts of biofuels, such as eutrophication, are indeed relevant and already contribute to significantly worsened environmental quality in certain regions. Changing agricultural practices with the relevant feedstock crop may mitigate some of the pressure, but will most probably not be sufficient to improve regional environmental conditions, such as water quality. This also indicates a limitation of the product life-cycle assessment approach, which does not account for the spatial pattern of environmental impacts resulting from the combined effects of increased biomass production.

Methodological constraints influencing results

The wide variation in LCA results reflects the plurality of technologies studied, and is also to a considerable extent due to varying assumptions and methodological constraints. Significant variation results from uncertainty about nitrous oxide (N_2O) emissions, which is a particularly strong GHG. Many life-cycle analyses have used the IPCC assessment methodology for estimating N_2O fluxes, which tends to give estimates only somewhat over 1% of the nitrogen applied in fertiliser. However, atmospheric balance calculations from Crutzen and colleagues have indicated that total emissions could range between 3 and 5%. If those values are corroborated, results of many LCA studies will have to be reconsidered.

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1 RFA (2008)

There are various other constraints which limit the comparability of LCA results and need to be considered when interpreting the results. For instance, results of life-cycle GHG balances may critically depend on the way land conversion related impacts are attributed. For instance, when oil palm plantations are established on converted natural forests and the associated emissions are depreciated over 100 years, GHG savings may result per hectare and year. Additional emissions will result if a depreciation period of 30 years is applied. When plantations are grown on tropical fallow (abandoned land), in general beneficial values result.

Improvement of the product chain oriented life-cycle approach seems necessary, and is ongoing, but basic deficiencies may be overcome only through the use of complementary analytical approaches which capture the overall impacts of biofuels in the spatial and socio-economic context. This is necessary in particular to account for the indirect effects of land use change induced by increased demand.

Impacts through increased demand and land use change

Actual and planned land use for crop production

Most of the currently used crops for transport biofuels are also food crops. Global land use for the production of fuel crops recently covered about 2% of global cropland (about 36 Mha in 2008). This development is driven by volume targets rather than by land use planning. The extension of cropland for biofuel production is continuing, in particular in tropical countries where natural conditions favour high yields. In Brazil, the planted area of sugar cane comprised 9 million hectares in 2008 (up 27% since 2007). Currently, the total arable land of Brazil covers about 60 Mha.The total cropping area for soybeans, which is increasingly being used for biodiesel, could potentially be increased from 23 Mha in 2005 to about 100 Mha. Most of the expansion is expected to occur on pasture land and in the savannah (Cerrado). In Southeast Asia, palm oil expansion – for food and non-food purposes – is regarded as one of the leading causes of rainforest destruction. In Indonesia, a further extension of 20 Mha for palm oil trees is planned, compared with the existing stock of at least 6 Mha. Two-thirds of the current expansion of palm oil cultivation in Indonesia is based on the conversion of rainforests, one third is based on previously cultivated or to-date fallow land. Of the converted rainforest areas, one quarter contained peat soil with a high carbon content - resulting in particularly high GHG emissions when drained for oil palms. By 2030, a share of 50% from peat soils is expected. If current trends continue, in 2030 the total rainforest area of Indonesia will have been reduced by 29% as compared to 2005, and would only cover about 49% of its original area from 1990.

Land requirements for projected biofuel use

Estimates of land requirements for future biofuels vary widely and depend on the basic assumptions made — mainly the type of feedstock, geographical location, and level of input and yield increase. There are more conservative trajectories which project a moderate increase in biofuel production and use, which have been developed as reference cases under the assumption that no additional policies would be introduced to further stimulate demand. These range between 35 Mha and 166 Mha in 2020. There are various estimates of potentials of biofuel production which calculate cropland requirements between 53 Mha in 2030 and 1668 Mha in 2050. About 118 to 508 Mha would be required to provide 10% of the global transport fuel demand with first generation biofuels in 2030 (this would equal 8% to 36% of current cropland, incl. permanent cultures).

Impacts of growing demand

A special concern is land use change induced by the growing demand for biofuels and the subsequent GHG emissions and consequences for biodiversity.

Clearing the natural vegetation mobilises the stocked carbon and may lead to a carbon debt, which could render the overall GHG mitigation effect of biofuels questionable for the following decades. The total CO_2 emissions from 10% of the global diesel and gasoline consumption during 2030 was estimated at 0.84 Gt CO_2, of which biofuels could substitute 0.17 to 0.76 Gt CO_2 (20-90%), whereas the annual CO_2 emissions from direct land conversion alone are estimated to be in the range of 0.75 to 1.83 Gt CO_2. Even higher emissions would result in the case of biodiesel originating from palm oil plantations established on drained peatland.

Current biofuel policies aim to implement production standards which require minimum GHG savings and assure that production land does not consist of recently converted natural forests, or other land with high value due to carbon storage or biodiversity. However, for net consuming regions like the EU and countries like Germany, models have shown that an increased use of biofuels would lead to an overall increase in absolute global cropland requirements. This implies that if biofuels are produced on existing cropland, other production - in particular for serving the growing food demand beyond the capacities to increase yields - will be displaced to other areas ("indirect land use"). As long as the global cropland required for agricultural based consumption grows, displacement effects, land conversion and related direct and indirect impacts may not be avoided through selected production standards for biofuels.

Increased biofuel production is expected to have large impacts on biological diversity in the coming decades, mostly as a result of habitat loss, increased invasive species and nutrient pollution. Habitat loss will mainly result from cropland expansion. Species and genotypes of grasses suggested as future feedstocks of biofuels may become critical as invaders. Nutrient emissions to water and air resulting from intensive fuel cropping will impact species composition in aquatic and terrestrial systems. Modelling the future biodiversity balance for different crops on different land types has shown that GHG reductions from biofuel production would often not be enough to compensate for the biodiversity losses from increased land use conversion, not even within a time frame of several decades. Beneficial effects for biodiversity have only been noted under certain conditions, when abandoned, formerly intensively used agricultural land or moderately degraded land is used. On such land, biofuel production can even lead to gains in biodiversity, depending on the production system used.

Options for a more efficient and sustainable production and use of biomass

Increasing yields and optimising agricultural production

The potential to increase yields differs among regions. In developing countries, crop and land productivity can be improved to increase production on existing cropland. Large potentials for increased yields seem to exist for instance in sub-Saharan Africa, where local cases have shown progress when both the use of agricultural technologies and the institutional setting have been improved. However, while increased investment into biofuels may evoke gains in agricultural productivity that could also spill over to food production, this remains to be proven and exacerbating the food versus fuel debate remains a concern. In countries with high crop yield levels, a constraint of rising importance is the increasing level of nutrient pollution. Adjusting crops and cultivation methods to local conditions may lead to efficiency increases and reduce environmental load. Genetic manipulation may be able to increase the lignocellulose yield for 2nd generation biofuels, although risks to the ecosystem remain uncertain and the precautionary principle should be considered. Altogether, the overall development at the global level will probably be a rather moderate increase of agricultural yields.

Restoring formerly degraded land

To avoid land use conflicts, degraded, "marginal", and abandoned land may be used for biofuel production. Certain crops, such as switchgrass, may even restore productivity of degraded land. While production may be less profitable, examples of small-scale biofuel projects, for instance with jatropha, demonstrate the potential for local energy provision. Nevertheless, crop and location specific challenges and concerns exist, especially regarding possible yields, required inputs and side-effects on water and biodiversity. While large potential areas have been suggested for both degraded and abandoned land, more research seems necessary to clarify the realistic production potentials, and to provide guidance for land management, in particular to balance the environmental costs and benefits of any land conversion against natural regeneration.

Using biomass for power and heat

Stationary use of biomass — to generate heat and/or electricity — is typically more energy efficient than converting biomass to a liquid fuel. It may also provide much higher CO_2 savings at lower costs. Indeed, even when considering advanced biofuels such as BtL, substituting fossil fuels for power and heat generation with wood may still save more GHG emissions. Stationary use technologies provide promising options for energy provision in developing countries for the community and households. The substitution of traditional biomass use for heating and cooking, for instance, may help overcome energy poverty and improve health conditions. In developed countries, state-of-the-art technology provides multifunctional services, for example by combining waste treatment with energy provision. Biogas is an example of a stationary use application thought to have particularly good potential as a renewable energy source with good GHG savings, especially when waste is used. Still, when energy crops are used for biogas, ecological and land use concerns need to be considered.

Use of waste and production residues

Energy recovery from waste and residues can save significant GHG emissions without requiring additional land. Specifically, municipal organic waste and residues from agriculture (both crop production and animal husbandry) and forestry provide a significant energy potential which is still largely unused. Further research is necessary to determine the proper balance of residues that should remain on the field or in the forest to maintain soil fertility and soil carbon content, and the amount that can be removed for energy, as well as with regard to nutrient recycling after energy recovery.

Cascading use of biomass

Using biomass to produce a material first, and then recovering the energy content of the resulting waste, can maximise the CO_2 mitigation potential of biomass. Through reutilisation more fossil fuel feedstock can be displaced with a smaller amount of biomass, and therefore also reduce the demand for land. This is particularly relevant as biomaterial production is expected to grow, and unchecked growth could lead to similar land use change concerns and constraints as biofuels. While cascading use may reduce competition between energetic and material biomass use, competition between uses may also hamper the prolongation of cascading chains. This can already be seen with certain forestry products and wood energy. Further research is required to determine the potential for cascading with regard to biomass uses (food, fibre, fuel and plastic) and resource requirements (land, primary materials and energy).

Mineral based solar energy systems

Like biomass, solar energy systems also transform solar radiation into useable energy, albeit much more efficiently. In particular, they have a significantly lower land requirement and may also be associated with less environmental impacts. While solar power is still subject to a cost disadvantage, this is expected to decrease and off-grid applications are already economically feasible. Further technologies, such as solar cookers, can substitute 'traditional biomass' use in developing countries. As such options provide services similar to biofuels, their application as potentially more beneficial alternatives for the local socio-cultural and ecological environment should be examined.

Strategies and measures to enhance resource productivity

Recent transport biofuel policies

Development of a biofuel industry has been largely fuelled by governments through mandates, targets and various mechanisms of support, such as subsidies, mainly for energy security. As negative environmental consequences of biofuels have come to light, these have come under scrutiny as being insufficiently supported by science. In particular, while mitigating climate change is a major driver behind biofuel support, the mitigation potential of biofuels to-date are rather minimal overall and the costs so far seem disproportionally high. For instance, according to OECD, subsidisation in the US, Canada and the EU represent between US$ 960 -1,700 per tonne of CO_2eq avoided in those countries. This level far exceeds the carbon value at European and US carbon markets. Although trade has been limited so far, it is expected to grow as a result of targets which will not be able to be met with domestic production in most countries.

To cope with rising concerns of unwanted side-effects of biofuels, some countries have started to promote criteria for sustainable bioenergy production. These standards and certification schemes rely on LCA based methods and often account only for selected impacts along the production chain. Further efforts are needed to fully consider not only GHG effects, but also other impacts such as eutrophication more comprehensively. Initiatives designed to protect small-scale farming in large-scale biofuel production, such as the social label in Brazil, also seem necessary. Whereas the improvement of the life-cycle-wide performance of biofuels (the "vertical dimension" at the micro level) may be fostered by certification, such product standards are not sufficient to avoid land use changes through increased demand for fuel crops (the "horizontal dimension" at the macro level). For that purpose, other policy instruments are needed which foster sustainable land use patterns and adjust demand to levels which can be supplied by sustainable production.

Fostering sustainable land use for biomass production

Increasing agricultural yields will be required for both food and non-food production. Key is mobilising potential in regions where productivity increases have lagged, such as sub-Saharan Africa. While a number of measures are required to overcome current constraints, the accelerated foreign investment in biofuel crops may lead to broader progress, although the benefit for local populations may also remain limited and should be monitored.

Cropland expansion, whether for food or non-food production, should not occur at the expense of high value natural ecosystems, also in light of ecosystem services. Various mechanisms are under development to shelter such lands, for example by providing them with an economic value, or agro-ecological zoning as currently being employed in the Brazilian Amazon. Limiting new fields to degraded land is another important strategy, but further research on the potential environmental costs and benefits is required.

Comprehensive land use management guidelines that consider agriculture, forestry, settlements/infrastructure/mining and nature conservation are needed on the regional, national and international levels for sustainable resource use. Countries need to monitor their actual and potential land use, taking the impacts of national resource consumption on the domestic and, where relevant, the global environment into account (incl. induced global land use change and subsequent GHG emissions).

Fostering more efficient use of biomass

In the future, advanced biofuels, such as cellulosic biofuels derived from timber processing residues, straw or corn stover, may be able to improve the resource efficiency of biofuels. However, more research on actual potentials, environmental impacts and land use requirements is needed.

As stationary use of biofuels for heat, power and CHP is generally more resource productive than for transport, policies may be devoted to prefer support of the former. Microfinance for stationary applications is a policy approach often employed in developing countries and feed-in tariffs have been used extensively in some developed countries. There is a need to research the possible global environmental consequences of increased stationary use, especially regarding the growing demand for forestry products for energetic use.

In various countries, policies have been established to promote recycling and energy efficiency of waste management. Feed-in tariffs can be used to foster market entry of power generated by waste and residues, or market-oriented measures, such as green pricing, can be used. As the criteria for what constitutes "green" is sometimes rather vaguely defined, such policies should be based on a comprehensive biomass strategy that considers both material and energetic use of non-food biomass.

Increase energy and material productivity in transport, industry and households

Global resources do not allow simply shifting from fossil resources to biomass while maintaining the current patterns of consumption. Instead, the level of consumption needs to be significantly reduced for biofuels to be able to substitute for relevant portions of fossil fuel use. For that to occur, resource efficiency in terms of services provided per unit of primary material, energy and land will need to be drastically increased. To this end, various developed and developing countries and international organisations have formulated goals and targets for increased resource productivity (Factor X).

Designing a policy framework by setting incentives for a more productive use of resources might be more effective and efficient in fostering a sustainable resource use than regulating and fostering specific technologies. For instance, economic instruments, such as transport fuel taxes, have reduced overall fuel consumption and GHG emissions in some countries.

Developing countries are challenged in finding the balance between increased energy supply and enhanced access on the one hand, and growing environmental impacts on the other hand. Increasing energy and material productivity is expected to approach that balance. For instance, China has set an ambitious target to enhance energy productivity by reducing energy intensity by 20% from 2005 to 2010.

The search for alternatives needs to go beyond alternative fuels.

Automotive industries are challenged to drastically reduce the fuel consumption of the car fleets they produce. Some countries have set regulatory standards towards this end. The automotive industry also has an interest to reduce fuel consumption and GHG emissions of their products. A concerted action could drive the world-wide development more quickly towards sustainability. A decisive step to this end could be a voluntary commitment of global automotive industries to reduce the GHG emissions and resource requirements of their products altogether by a significant amount within the years to come.

Altogether, various strategies and measures can be used to further develop policies which can effectively contribute to a more efficient and sustainable use of biomass and other resources.

Section 1: **Introduction**

Climate change, together with an increasing demand for energy, volatile oil prices, and energy poverty have led to a search for alternative sources of energy that would be economically efficient, socially equitable, and environmentally sound. One option that has raised enormous public and private interest, is biofuels. Farmers seek additional income and biofuels may have the potential to promote rural development and access to energy in poorer countries. As a 'readily available' alternative, biofuels offer to continue business as usual in the transport sector. Encouraged by research indicating that biofuels could provide substantial energy while mitigating climate change, governments have suported production aimed at increasing biofuel use in many countries. Industry has invested significantly in production and technology development.

However, concern has been growing about negative implications of growing biomass for biofuel production. Current biofuels are often made from feedstock crops that also serve as food. Hence, there is a potential risk for competition between food and fuel, and consequences on food prices as a result. Another risk identified is expansion of biofuel feedstock production into areas that provide valuable ecosystems that support high biodiversity and services that are crucial to our economies and human life. Moreover, as a consequence of land use change associated with expanding agriculture, the envisaged positive effects on climate mitigation could turn out to have the opposite effect.

To deal with these issues, several initiatives have been started by governments, industry players and civil society to develop criteria for sustainable production of biofuels (see Boxes A.1 and A.2 in the appendix). Countries have started to set minimum standards for biofuels, in order to guarantee a net benefit for climate change mitigation and to avoid side-effects of land use change. These approaches, however, are aimed at the product or project level and are therefore not necessarily sufficient to avoid displacement of feedstock production and problem shifting to other areas. The question remains whether a significant expansion of biofuel production could be **"too much of a good thing."**

The Biofuels Working Group of the International Panel for Sustainable Resource Management aims to improve the analytical basis for decision making towards sustainable production and use of biomass for energy purposes ("biofuels"), at the international, regional and national level.

Applying a comprehensive systems perspective, the analysis presented here covers the overall effects of biomass use for food, fibre and fuel, in particular on land and water use and resulting environmental impacts such as greenhouse gas emissions, biodiversity loss, and nutrient pollution. The focus is on the environmental effects of so-called "modern bioenergy" or biofuels, while considering their economic aspects and social concerns, especially with regard to relevant side-effects and potential synergies. The report does not address traditional unprocessed biomass like fuel wood, but includes agricultural residues, forest products waste, and municipal waste that can be used to provide electricity and heat for households and industrial processing. The report provides an overview of key problems and perspectives relating to sustainable production and use of modern biofuels. It is a synthesis of the extensive literature available to the end of 2008 with a few more recent articles of particular relevance considered as well. It does not claim to be the "final word", as research in the field of biofuels is experiencing rapid growth (especially related to more advanced biofuels). The report mainly covers first-generation biofuels unless otherwise specified. This is solely due to the availability of literature in the reviewing period, and does not mean that more advanced biofuels would not need a similar extensive review of potential risks and benefits.

Significant options for future progress go beyond the optimisation of biofuel production. An integrated view of supplying both materials and energy for enhanced service provision for households and industry will lead to wider potentials and allow better choices to increase sustainability of resource use. Improved systems technologies will enhance overall resource efficiency, while more effective management instruments can adjust the demand for biofuels to sustainable levels.

Section 2: **Types of biofuels**

Biofuels are combustible materials directly or indirectly derived from biomass, commonly produced from plants, animals and micro-organisms but also from organic wastes. Biofuels may be solid, liquid or gaseous and include all kinds of biomass and derived products used for energetic purposes[2]. This "bioenergy" is one of the so-called renewable energies. Besides the traditional use of bioenergy[3], 'modern bioenergy' comprises biofuels for transport, and processed biomass for heat and electricity production.

Biofuels for transport are commonly addressed according to their current or future availability as first, second or third generation biofuels (OECD/IEA 2008). Second and third generation biofuels are also called "advanced" biofuels. UNEP (2008) points out that this differentiation is not always straightforward due to overlaps regarding feedstocks and processing technologies, as well as uncertainties regarding environmental impacts. Terms such as "higher generation" or more "advanced" biofuels suggest superiority; however, superiority in terms of sustainability is not a given and needs to be assessed as critically as for all kinds of biofuels.

'First-generation biofuels' are commercially produced using conventional technology (Table 2.1). The basic feedstocks are seeds, grains, or whole plants from crops such as corn, sugar cane, rapeseed, wheat, sunflower seeds or oil palm. These plants were originally selected as food or fodder and most are still mainly used to feed people. The most common first-generation biofuels are bioethanol (currently over 80% of liquid biofuels production by energy content), followed by biodiesel, vegetable oil, and biogas.

Second-generation biofuels can be produced from a variety of non-food sources. These include waste biomass, the stalks of wheat, corn stover, wood, and special energy or biomass crops (e.g. Miscanthus). Second-generation biofuels use biomass to liquid (BtL) technology, by thermochemical conversion (mainly to produce biodiesel) or fermentation (e.g. to produce cellulosic ethanol). Many second-generation biofuels are under development such as biohydrogen, biomethanol, DMF, Bio-DME, Fischer-Tropsch diesel, biohydrogen diesel, and mixed alcohols.

Algae fuel, also called oilgae, is a biofuel from algae and addressed as a **third-generation biofuel** (OECD/IEA 2008). Algae are feedstocks from aquatic cultivation for production of triglycerides (from algal oil) to produce biodiesel. The processing technology is basically the same as for biodiesel from second-generation feedstocks.

Other **third-generation biofuels** include alcohols like bio-propanol or bio-butanol, which due to lack of production experience are usually not considered to be relevant as fuels on the market before 2050 (OECD/IEA 2008), though increased investment could accelerate their development. The same feedstocks as for first-generation ethanol can be used, but using more sophisticated technology. Propanol can be derived from chemical processing such as dehydration followed by hydrogenation. As a transport fuel, butanol has properties closer to gasoline than bioethanol.

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[2] incl. heating/cooling, process energy like cooking, electricity, and transport

[3] Traditional biomass means unprocessed biomass, including agricultural waste, forest products waste, collected fuel wood, and animal dung, that is burned in stoves or furnaces to provide heat energy for cooking, heating, and agricultural and industrial processing, typically in rural areas.

Table 2.1: **Types of biofuels – overview with basic technologies, important feedstocks and examples of co-products**

Biofuel	Basic technology	Feedstocks	Co-products
Solid biofuels *	Traditional use of dried biomass for energy	Fuel wood, dried manure	
First generation biofuels			
Plant oils **	1) As transport fuel: Either adaptation of motors to the use of plant oils; or modification of plant oils to be used in conventional motors 2) For generation of electricity and heat in decentralised power resp. CHP stations	1) Rapeseed oil, sunflower, and other oil plants, waste vegetable oil 2) Rapeseed oil, palm oil, jatropha, and other oil plants	Oilcake as animal feed
Biodiesel	Transesterification of oil and fats to provide fatty acid methyl ester (FAME) and use as transport fuel	- Europe: Rapeseed, sunflower, soya - USA: Soya, sunflower; - Canada: Soya, rapeseed (Canola) - South- and Central-America: Soya, palm, jatropha, castor - Africa: Palm, soya, sunflower, jatropha - Asia: Palm, soya, rapeseed, sunflower, jatropha	- Oilcake as animal feed; - Glycerine; - Oilcake in some palm oil mills used for energy recovery
Bioethanol	Fermentation (sugar); hydrolysis and fermentation (starch); use as transport fuel	- USA: Corn - Brazil: Sugar cane - Other South- and Central-America: Sugar cane, cassava - Europe: Cereals, sugar beets - Canada: Maize, cereals; - Asia: Sugar cane, cassava; - Africa: Sugar cane, maize	- Maize and cereals yield animal feed DDGS (Dried Distillers Grains with Solubles). - Sugar cane bagasse is used for energy recovery
Biogas (CH_4, CO_2, H_2)	Fermentation of biomassused either in decentralised systems or via supply into the gas pipeline system (as purified biomethane); 1) For generation of electricity and heat in power resp. CHP stations 2) As transport fuel: either 100% biogas fuel or blending with natural gas used as fuel	Energy crops (e.g. maize, miscanthus, short rotation wood, multiple cropping systems); biodegrable waste materials, including from animal sewage	Residues used as fertiliser (nutrient recycling)
Solid biofuels	1) Densification of biomass by torrefaction or carbonisation (charcoal); 2) Residuals and waste for generation of electricity and heat (e.g. industrial wastes in CHP)	Wood, grass cuttings, switchgrass; grains; charcoal, domestic refuse, and dried manure	

Second generation biofuels			
Bioethanol	Breakdown of cellulosic biomass in several steps incl. hydrolysis and finally fermentation to bioethanol	Ligno-cellulosic biomass like stalks of wheat, corn stover and wood; special-energy-or-biomass crops (e.g. Miscanthus); sugar cane bagasse	
Biodiesel and range of "designer"-biofuels such as biohydrogen, biomethanol, DMF***, Bio-DME****, mixed alcohols	Gasification of low-moisture biomass (<20% water content) provides "syngas" (with CO, H_2, CH_4, hydrocarbons) from which liquid fuels and base chemicals are derived	Ligno-cellulosic biomass like wood, straw, and secondary raw materials like waste plastics	Fischer-Tropsch synthesis can be used to produce various feedstocks for chemical industry (not only for fuel but also e.g. plastics)
Third generation biofuels			
Biodiesel, aviation fuels, bioethanol, biobutanol	Bioreactors for ethanol (production can be linked to sequestering carbon dioxide from power plants); Transesterification and pyrolysis for biodiesel; other technologies under development	Marine macro-algae micro-algae in ponds or bioreactors	High-protein animal feed,biopolymers, agricultural fertilisers

[*] Traditional use of biomass included for complete overview

[**] Also known as straight vegetable oil. Plant oil used as direct fuel in transport is common in German agriculture with about 838,000 tonnes mostly rapeseed oil in 2007, representing 1.4% of total fuel consumption in transport.

[***] 2,5-Dimethylfuran.

[****] Dimethyl ether

Source: own compilation after different sources

Section 3: **Important trends and drivers**

This section will focus on trends and drivers specific to biofuels. While recognising the importance of the many other forms of energy – both non-renewable and renewable – consideration of comprehensive energy scenarios would be beyond the scope of this report.

An important factor for the future supply of biomass from agricultural land will be the development of agricultural yields, especially in relation to climate change globally and regionally. The development of global food demand with changing consumption patterns towards more animal based nutrition will also influence the requirement for agricultural land.

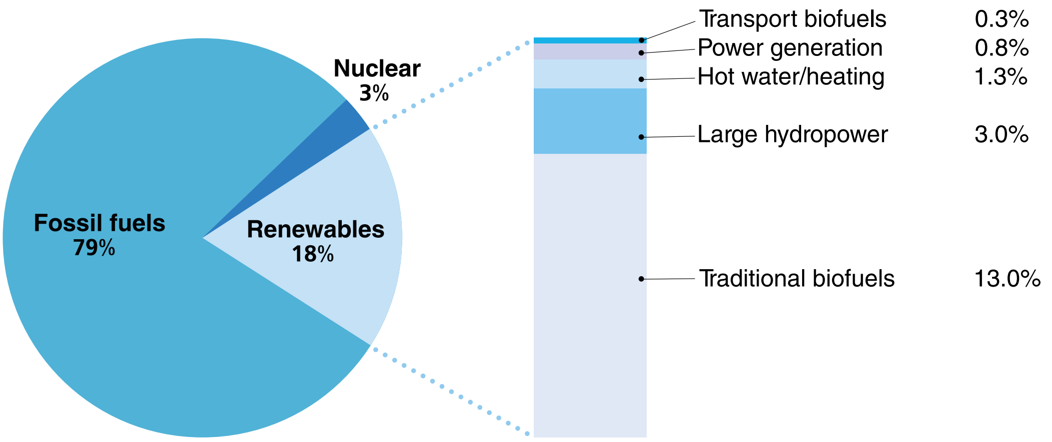
3.1. Current and projected use and potentials of biofuels

So far, "modern" biomass use constitutes only a negligible share of total global energy consumption. For example, first generation biofuels for transport provided only 0.3% of global final energy consumption (GFEC) in 2006 and 1.8% of total transport fuels in 2007 (OECD/FAO 2008).

Traditional biomass accounted for about 13% of global final energy demand in 2006, the largest contribution to all renewable energies which together accounted for 18% (Fig. 3.1). Renewables for power generation contributed 0.8% to global final energy demand in 2006, but the share of biomass to this is not recorded. The same applies for hot water/heating, which contributed 1.3% to GFEC.

While traditional biomass constitutes an important part of the energy mix, so far modern biomass use makes up only a small share of total global energy consumption.

Figure 3.1: **Renewable energy share of global final energy consumption (GFEC) in 2006**



Source: REN21 (2008)

Modern biomass use for heat and power receives increasing attention, both in developed and developing countries.

3.1.1. Biomass for power and heat

In developing countries, over 500 million households still use traditional biomass for cooking and heating. However, already 25 million households cook and light their homes with biogas (displacing kerosene and other cooking fuel); and a growing number of small industries, including agricultural processing, obtain process heat and motive power from small-scale biogas plants.

Biomass power contributed about 1% to the total global electric power capacity of 4300 GW in 2006. Of the existing total global renewable capacity for electricity generation (excluding large hydro) 22% were from biomass (Table 3.1). Developing countries had established about half of the global biomass for power capacity, more than twice the contribution of the EU-25 and nearly three times that of the USA (Fig. 3.2). For the hot water and heating sector, traditional biomass heating still provides the largest share of heating from renewables globally.

Biomass is to a growing extent employed for both power and heating, with recent increases in biomass use in European countries, particularly Austria, Denmark, Germany, Hungary, the Netherlands, Sweden, and the United Kingdom, and in some developing countries. The use of biomass for district heating and combined heat-and-power (CHP) has been expanding in Austria, Denmark, Finland, the UK, Sweden, and the Baltic countries, and provides substantial shares of district heating (5–50%, depending on countries' natural resources availability). In Europe two-thirds of biomass is used for heating.

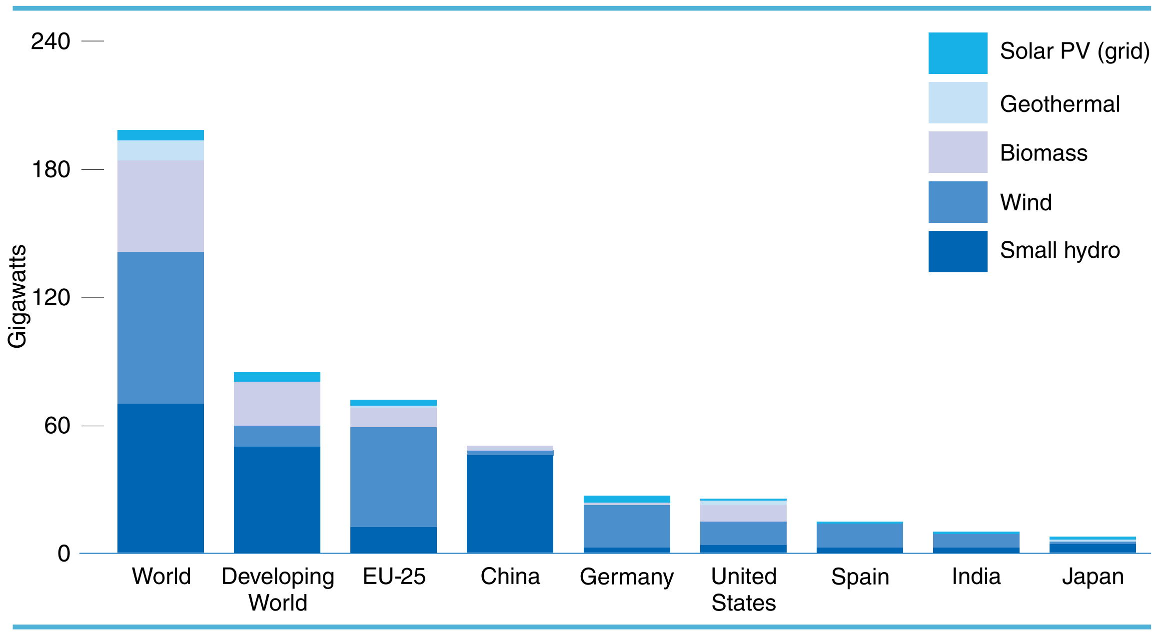
Among developing countries, heat production from agricultural waste is common and small-scale power is increasingly being deployed, for example from rice or coconut husks. The use of bagasse (sugar cane after juice extraction) for power and heat production is significant in countries with a large sugar industry. Wood pellets from forest and timber processing residues have become more common, with about 800,000 homes in the US currently using

Table 3.1: **Global renewable energy added during 2006 and existing capacities as of 2006**

	Added during 2006	Existing at end of 2006
Power generation (GW)		
Large hydropower	12-14	770
Wind turbines	15	74
Small hydropower	7	73
Biomass power	n/a	45
Geothermal power	0.2	9.5
Solar PV, grid-connected	1.6	5.1
Solar PV, off-grid	0.3	2.7
Concentrating solar thermal power (CSP)	<0.1	0.4
Ocean (tidal) power	~0	0.3
Hot water/heating (GWth)		
Biomass heating	n/a	235
Solar collectors for hot water/heating (glazed)	18	105
Geothermal heating	n/a	33
Transport fuels (GW)		
Ethanol production	3.4	26
Biodiesel production	2.2	6

Source: modified after REN21 (2008)

Figure 3.2: **Renewable power capacities of the developing world, EU, and top six countries in 2006**



Note : Excludes large hydropower

Source: REN21 (2008)

pellets[4] and 6 million tons consumed in Europe in 2005, about half for residential heating and half for power generation (often in small-scale CHP plants). The main European countries employing pellets are Austria, Belgium, Denmark, Germany, Italy, the Netherlands, and Sweden. A global division of biomass consumption for heating versus power is not available.

By 2007, at least 64 countries had a national target for renewable energy supply, including all 27 European Union countries (Table 3.2). In addition to those countries, several U.S. states and Canadian provinces have policy targets concerning renewable energy, although neither the United States nor Canada has a national target (targets for transport fuels are discussed below). National targets for shares of electricity production are typically 5–30 percent, but ranging altogether from 2 percent to 78 percent. Other targets include shares of total primary or final energy supply, specific installed capacity, or total amounts of energy production from renewables.

Policy targets for renewable energy are seldom explicit for the share of biomass amongst other sources, not to mention a consistent breakdown of different uses of biomass. However, China's national renewable energy target is 15 percent of primary energy by 2020, including 30 GW of biomass (less than 10% of the total renewable target). Meeting the target would almost triple China's renewable energy capacity by 2020.

Among developing countries, heat production from agricultural waste is common and small-scale power is increasingly being deployed.

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[4] According to the Pellet Fuels Institute, accessed February 19, 2009, www.pelletheat.org

Table 3.2: **Share of primary and final energy from renewables, existing in 2006 and targets**

	Primary energy (IEA method)		Final energy (EC method)	
Country/region	**Existing share (2006)**	**Future target**	**Existing share (2005 - 06)**	**Future target**
World	13.0%	-	18.0%	-
EU-25/EU-27	6.5%	12% by 2010	8.5%	20% by 2020
Selected EU countries				
Austria	20.0%	-	23.0%	34% by 2020
Czech Republic	4.1%	8-10% by 2020	6.1%	13% by 2020
Denmark	15.0%	30% by 2025	17.0%	30% by 2020
France	6.0%	7% by 2010	10.0%	23% by 2020
Germany	5.6%	4% by 2010	5.8%	18% by 2020
Italy	6.5%	-	5.2%	17% by 2020
Latvia	36.0%	6% by 2010	35.0%	42% by 2020
Lithuania	8.8%	12% by 2010	15.0%	23% by 2020
Netherlands	2.7%	-	2.4%	14% by 2020
Poland	4.6%	14% by 2020	7.2%	15% by 2020
Spain	6.5%	12.1% by 2010	8.7%	20% by 2020
Sweden	28.0%	-	40.0%	49% by 2020
United Kingdom	1.7%	-	1.3%	13% by 2020
Other developed/OECD countries				
Canada	16.0%	-	20.0%	-
Japan	3.2%	-	3.2%	-
Korea	0.5%	5% by 2011	0.6%	-
Mexico	9.4%	-	9.3%	-
United States	4.8%	-	5.3%	-
Developing countries				
Argentina	8.2%	-	-	-
Brazil	43.0%	-	-	-
China*	8.0%	15% by 2020	-	-
Egypt	4.2%	14% b 2020	-	-
India	31.0%	-	-	-
Indonesia	3.0%	15% by 2025	-	-
Jordan	1.1%	10% by 2020	-	-
Kenya	81.0%	-	-	-
Mali	-	15% by 2020	-	-
Morocco*	4.3%	10% by 2010	-	-
Senegal	40.0%	15% by 2025	-	-
South Africa	13.0%	-	-	-
Thailand*	4.0%	8% by 2011	-	-

Note: Not all countries with primary energy targets are included in table. Targets for final energy by 2020 for EU countries were proposed in January 2008 by the European Commission and were subject to review and confirmation by the member countries. Final energy existing share is 2005 for EU countries and 2006 for world and other countries. EU primary energy target by 2010 applies to EU-25; final energy target by 2020 applies to EU-27.
(*) Existing share and targets for China, Morocco, and Thailand exclude traditional biomass.
Some countries shown also have other types of targets.

Source: REN21 2008

Uncoordinated targets for renewables and biofuels without an overall biomass strategy may enhance competition for biomass. Power and transport fuels often depend on the same biomass feedstocks, or at least on the same available cropland. Therefore, some national targets may only be implemented by increased imports, thus contributing to proliferating competition for biomass globally. An overall biomass strategy would have to consider all types of use of food and non-food biomass.

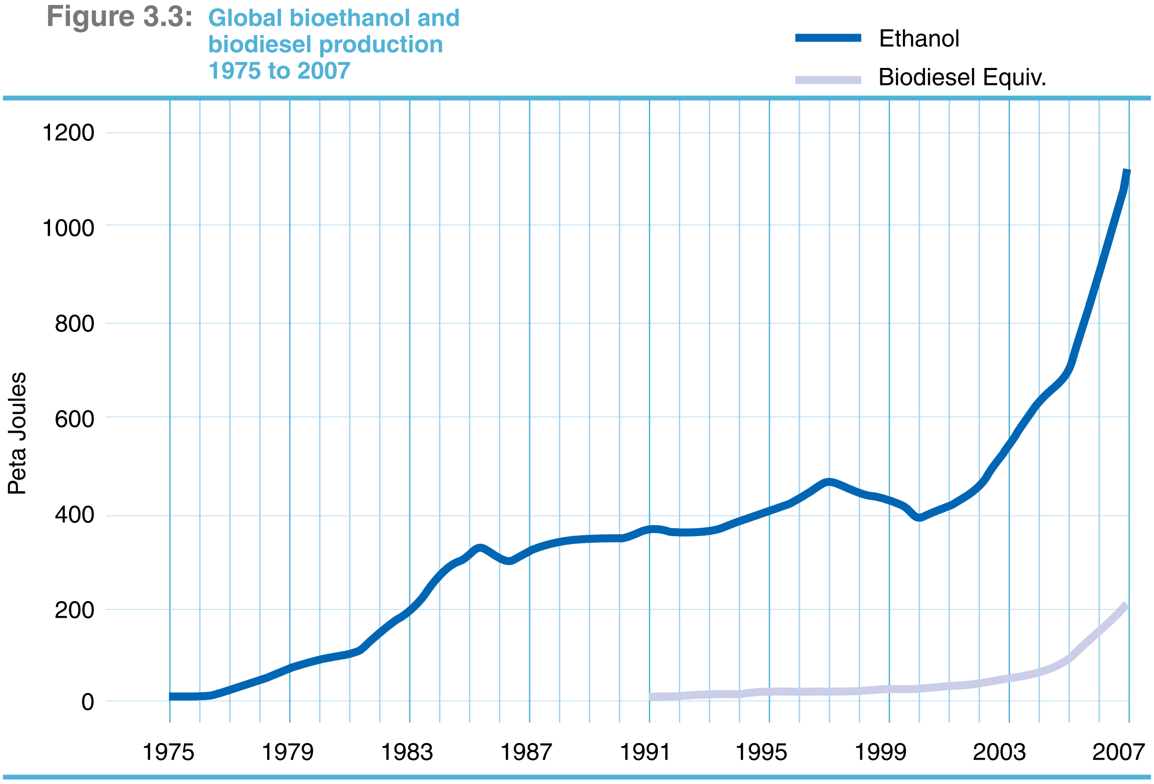
More and more countries are putting into place renewable energy and biofuel targets. They should be complemented with an overall biomass strategy to address the issue of competition for biomass use.

3.1.2. Biofuels for transportation

Primarily driven by government policies, world ethanol production for transport fuel tripled between 2000 and 2007 from 17 billion to more than 52 billion litres, while biodiesel expanded eleven-fold from less than 1 billion to almost 11 billion litres (Fig. 3.3). These fuels together provided 1.8% of the world's transport fuel by energy value (36 Mtoe out of a total of 2007 Mtoe) (OECD 2008). In Europe there has been a continuing increase in the use of biofuels in road transport over the past decade from 0.1% in 1997 to 2.6% in 2007 (EEA 2008 a,b).

World ethanol production for transport fuel tripled between 2000 and 2007 while biodiesel expanded eleven-fold.

Figure 3.3: Global bioethanol and biodiesel production 1975 to 2007



Source: SCOPE (2009)

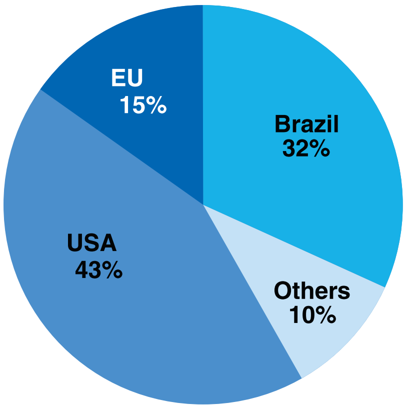
Production significantly increased in the United States, Brazil, the EU, Canada and China.

Current use of biofuels for transport on the global scale is dominated by bioethanol and biodiesel, whereas use of other biofuels for transport like biogas and pure plant oil seem to be restricted to local and regional pilot cases, and second-generation biofuels are still in the development stage. Commercial investment in advanced (second-generation) biofuel plants is beginning in Canada, Germany, Finland, Japan, the Netherlands, Sweden, and the United States (REN21 2008; EEA 2008a,b).

A recent estimate for 2008 by OECD/FAO (2008) arrives at 64.5 billion litres ethanol and 11.8 billion litres biodiesel, up 22% from 2007 (by energy content). From 2005-2007 (average) to 2008, the share of ethanol in global gasoline type fuel use has increased from 3.78% to 5.46%, the share of biodiesel in global diesel type fuel use from 0.93% to 1.5% (OECD/FAO 2008).

The main producing countries for transport biofuels are the USA, Brazil, and the EU (Fig. 3.4). Production in the United States was mostly ethanol from corn, in Brazil was ethanol from sugar cane, and in the European Union was mostly biodiesel from rapeseed.

Figure 3.4: Proportion of global production of liquid biofuels in 2007



Source: SCOPE policy brief 2009

In recent years, production significantly increased in the United States, Brazil, the EU, Canada and China. The United States became the leading fuel ethanol producer in 2006, producing over 18 billion litres. Even so, US ethanol imports increased six-fold. US ethanol production is expected to further increase and reach 38 billion litres in 2008, up 43% from 2007, representing more than half (58%) of global production (OECD/FAO 2008).

Brazilian ethanol production increased to 22.5 billion litres in 2008, or 29% of the world's total (OECD/FAO 2008)[5]. All fueling stations in Brazil sell both pure ethanol and a 25% ethanol/75% gasoline blend. Back in 1984, the average car sold in Brazil could run only on (hydrated) ethanol. Then the ethanol market collapsed, and gasoline-only cars dominated. As of today, some 90% of all auto sales in Brazil are so-called "flex fuel" cars, i.e. cars able to use both, and which require anhydrous ethanol, contributing to about half of the demand for ethanol fuels. Biofuel demand has regrown to levels similar to 1983.

Biodiesel production was expected to reach about 12 billion litres globally in 2008, up 20% from 2007 (OECD/FAO 2008). Half of the world biodiesel production continued to be in the EU-27, in particular in Germany. Production also increased from 2007 to 2008 in the United States, Australia, Brazil, Indonesia and Malaysia, though from a low base and production in these countries is still very low. In Europe, supported by new policies, biodiesel gained broader acceptance and a higher market share. Biodiesel production also expanded in Malaysia, Indonesia, Singapore, China, Argentina, Brazil, Romania and Serbia. Malaysia's ambition is to capture 10% of the global biodiesel market by 2010 based on its palm oil plantations. Indonesia also planned to expand its palm oil plantations by 1.5 Mha by 2008, to reach 7 Mha total, as part of a biofuels expansion program that includes $100 million in subsidies for palm oil and other biofuels from soy and maize.

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[5] Data regarding the Northeastern region are still preliminary for the 2007/2008 harvest year. Data provided by the Brazilian Sugarcane Industry Association – UNICA and Ministry of Agriculture, Livestock and Food Supply –MAPA (http://english.unica.com.br/dadosCotacao/estatistica/).

New biodiesel capacity has developed throughout Europe, amounting to almost 7 billion litres/year at the end of 2006. Among developing countries, Argentina had a 0.7 billion litres production capacity in 2007, exporting more than half of domestic production. The capacity was projected to double by 2008. Brazil is expected to have reached a 760 million litres biodiesel production capacity by 2008, mostly for domestic use. Plans for new biodiesel plants and/or increased palm oil and Jatropha plantations were announced in several countries during 2006/2007.

The recent economic crisis led to a decline of oil prices and reduced the demand for first-generation biofuels, affecting various production facilities. For example, many of the biodiesel plants in Argentina were not working at the beginning of 2009. One may assume that the former trends might be resumed with a recovering world economy.

Serious commercial investment in second-generation biofuels began during 2006/2007 in many countries, like Canada, the United States, Japan and in the EU (REN21 2008). The world's first commercial wood-to-ethanol plant run by BioEthanol Japan Kansai Co. began operation in Osaka in 2007, with a capacity of 1.4 million litres/year. In the US, the first commercial cellulosic ethanol facility to convert waste wood materials into a renewable fuel went into production near Upton, Wyoming in 2008, run by KL Process Design Group. In Europe, the Dutch firm Royal Nedalco was building a $200 million plant that would produce 200 million litres/year from wheat chaff and other wastes by late 2008.

International trade in ethanol and biodiesel has been small so far (OECD 2008). Global trade in fuel ethanol is estimated to have been about 3 billion litres per year over 2006/07 (Fig. 3.5 shows total ethanol trade because the distinction in trade statistics is difficult given that fuel and non-fuel ethanol often share the same tariff lines at the level trade is reported). This was about 7% of global bioethanol production. For some countries like Brazil, trade can play an increasingly important role, demonstrated by a record-high of 5.16 billion litres of ethanol fuel exported in 2008, according to a report by the Ministry of Mines and Energy[6]. International biodiesel exports in 2007 amounted to some 1.3 billion litres (Fig. 3.6), about 12% of global production. One may expect that the volume of international trade in biofuels will grow further, in particular, as policy targets of net consuming countries will require increasing imports.

International trade in ethanol and biodiesel has been small so far, but it is expected that the volume of international trade in biofuels will grow.

Policies have stimulated biofuel demand by setting targets and blending quotas, and have aided development by establishing support mechanisms (such as subsidies and tax exemptions, see section 7.1). Mandates for blending biofuels into vehicle fuels had been enacted in at least 36 states/provinces and 17 countries at the national level by 2006 (Table 3.3). Most mandates require blending 10–15% ethanol with gasoline or blending 2–5% biodiesel with petroleum diesel.

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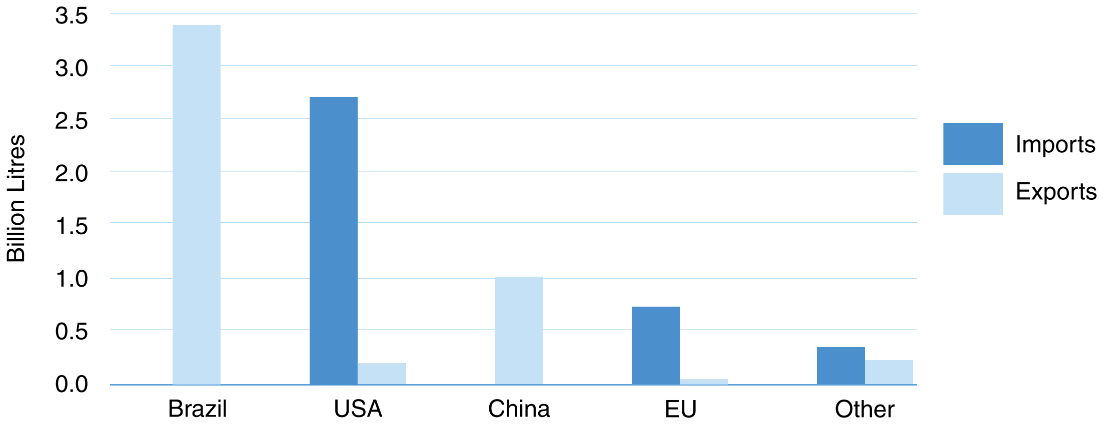
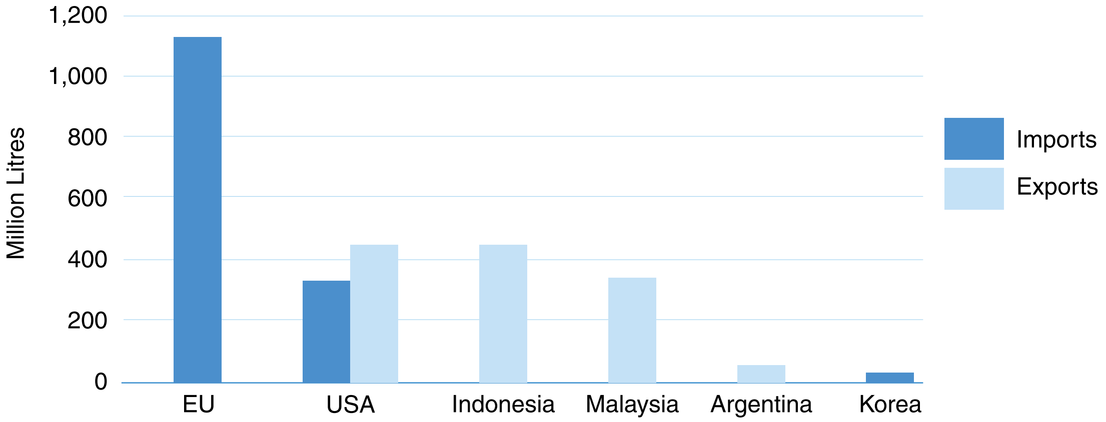
[6] As reported by http://bioenergy.checkbiotech.org/news/brazil_registers_record_high_ethanol_fuel_export

Figure 3.5: International trade in ethanol in 2006



Source: OECD 2008 – data compiled from F.O. Licht's (2008)

Figure 3.6: International trade in biodiesel in 2007



Source: Data compiled from LMC (2007a)

Brazil has been the world leader in mandated blending of biofuels for 30 years under its "ProAlcool" program. The blending shares are adjusted occasionally, but have remained in the range of 20–25%. All gas stations are required to sell both gasohol (E25) and pure ethanol (E100). The blending mandate has also been accompanied by a host of supporting policies, including retail distribution requirements and tax preferences for vehicles.

In addition to mandated blending, several new biofuels targets and plans appeared during 2006/2007, defining future levels of biofuels use (Table 3.3). A new US renewable fuels standard implies that 20% of gasline for road transport would be biofuels by 2022.

In 2007, the German government proposed a national total biofuels target of 17% of energy consumption for road transport by 2020. In 2008, this target was reduced to 12-15% energetic biofuels contribution for technical reasons and then later, in light of increasing concerns over the global implications and negative climate impacts of biofuels, the government decided to reduce its mandatory blending quota to 6.25% from 2010. The decision also requires to keep this quota until 2014, and to review the target in 2011 based on up-dated scientific evidence and improved protocols.

The EU has adopted a new EU-wide binding target of 10% of transport energy from renewable sources by 2020 (EU 2009b). Various fuels may contribute (incl. electricity) as long as they are based on renewable sources, and only alternative fuels which meet set GHG savings and limits on impacts in particular to biodiversity will count towards the legal quota. According to the directive, member states shall promote and encourage energy efficiency and energy saving. In light of recent research addressing the impacts of biofuels, the use of biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material are favoured over the use of first-generation biofuels. The net effects from the use of alternative fuels instead of currently available first-generation biofuels remains to be investigated.

Table 3.3: Overview of the global use of biofuels for transport during 2005-2007, blending mandates and total biofuels targets, volumes required per year to reach targets

	Fuel ethanol plus biodiesel in 2005-2007				Blending mandates		Biofuel targets	Volumes required per year	
	billion litres	%	Mt	PJ	Bioethanol	Biodiesel	Biofuels total	Bioethanol	Biodiesel
Canada	0.781	1.67%	0.62	17	E5 by 2010	B2 by 2012			
USA	21.946	46.86%	17.41	473			20% by 2022	130 billion litres by 2022*	
EU Total	7.563	16.15%	6.64	226			10% by 2020		
Australia	0.262	0.56%	0.22	8	regional only				
Japan	0.000	0.00%	0.00	0			5% by 2030	6 billion litres by 2030	
South Africa	0.000	0.00%	0.00	0	E8-E10 proposed	B2-B5 proposed	4.5% biofuels		
Ethopia	0.002	0.00%	0.00	0					
Mozambique	0.001	0.00%	0.00	0					
Tanzania	0.004	0.01%	0.00	0					
Brazil	13.657	29.16%	10.80	290	E22 to E25 exist.	B5 by 2013			
Columbia	0.268	0.57%	0.21	6	E10 exisiting	B5 by 2008			2.5 billion litres by 2013
Peru	0.000	0.00%	0.00	0	E7.8 by 2010	B5 by 2010			
China	1.565	3.34%	1.24	33	E10 in 9 provinces			13 billion litres by 2020	
India	0.544	1.16%	0.45	15	E10 in 13 regions				2.3 billion litres by 2020
Indonesia	0.047	0.10%	0.04	2					
Malaysia	0.000	0.00%	0.00	0		B5 by 2008			
Philippines	0.017	0.04%	0.01	0	E10 by 2011	B2 by 2011			
Thailand	0.134	0.29%	0.11	3	E10 by 2007	3% share by 2011			
Turkey	0.043	0.09%	0.03	1					
World Total	**46.834**	**100.00%**	**37.63**	**1073**					
Argentina					E5 by 2010	B5 by 2010			
Bolivia						B20 by 2015			
Croatia							5.75% by 2010		
Dominican Republic					E15 by 2015	B2 by 2015			
New Zealand							3.4% by 2012		
Paraguay						B5 by 2009			
Uruguay					E5 by 2014	B5 by 2012			
Belgium							5.75% by 2010		
France							10% by 2015		
Germany					E2 by 2007	B4.4 by 2007	12-15% by 2020	1.45 billion litres by 2020	8.3 billion litres by 2020
Italy					E1	B1			
Portugal							10% by 2010		
UK					E5 by 2010	B5 by 2010			
billion l from cellulosic ethanol									

Note 1: Mandates and blending quota may refer to shares based either on volume or energy content (which is often not clear). According to the lead author of the REN21 (2007) report, blending mandates generally refer to volume, while percentage targets generally refer to share of transport energy content, but the author assumes that there are exceptions and is not absolutely sure about it (personal communication by Email from Mr. Martinot of 21 October 2008). In the case of biodiesel shares referring to energy content require about 10% more volume, in the case of ethanol even 50% more volume, as the energy content of these biofuels is lower than that of fossil fuels.
Note 2: the 10% biofuels target of the EU for 2020 refers to 10% energy from all renewables sources in all forms of transport.
* of which are: ca. 50 billion l from corn based ethanol, ca. 80 billion l from cellulosic ethanol.

Source: own compilation based on REN21 (2008) and OECD/FAO (2008)

3.1.3. Future potentials and projected use of biofuels

The potential of biofuels largely depends on the availability of land appropriate for producing the various feedstocks.

Table 3.4 provides a synthesis of analyses of the theoretical longer-term potential of biomass availability on a global scale. Also, a number of uncertainties are highlighted that can affect biomass availability. These estimates are sensitive to assumptions about crop yields and the amount of land that could be made available for the production of biomass for energy uses. Critical issues include:

- Competition for water resources:
  Irrigation may be necessary for economically viable outputs in countries where water is already scarce.
- Use of fertilisers and pest control techniques:
  Improved farm management and higher productivity usually imply increasing use of fertilisers and appropriate pest control.
  This may lead to increased pollution from nutrients and biocides.
- Intensive versus extensive farming:
  More intensive farming to produce energy crops may require less extension of land than extensive cropping of lower yield feedstocks, but with opposite effects on field biodiversity.
  More intensive cattle-raising would also be necessary to free up grassland currently used for grazing.
- Competition with food and feed production:
  If the total demand increases faster than yields, agriculture could drive up land and food prices, and contribute to further land use changes.
- Uncertainties resulting from climate change, in particular with regard to further yield increases and the hazard of extreme weather events which may lead to regional and local yield shocks.

These critical issues will be considered in more detail in subsequent section.

The data in Table 3.4 comprises studies with rather optimistic assumptions[7]. With a more realistic perspective, and considering environmental limitations, the Scientific Council on Global Environmental Change of the German Government estimated the economically viable and sustainable potential for global bioenergy (energy crops and waste/residues) to amount to 40 to 85 EJ/a by the middle of this century (WBGU 2008).

In a short to medium term reference scenario, the IEA (2007a) expects a rather moderate development for biomass and waste to contribute 56 EJ/a in 2015 and 68 EJ/a in 2030 (Table 3.5). The share of biomass and waste of total global primary energy supply would decrease from 10% in 2005 to 9% in 2030. Biofuels for transport would increase from 0.8 EJ in 2005 to 2.4 EJ in 2015 and 4.3 EJ in 2030, contributing increasing shares of up to 0.9% in 2030 to global total energy consumption.

The potential of biofuels largely depends on the availability of land appropriate for producing the various feedstocks.

With a more realistic perspective, the economically viable and sustainable potential for global bioenergy (energy crops and waste/residues) could amount to 40 to 85 EJ by the middle of this century.

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[7] Some of the underlying assumptions are highly controversial: Note that Field et al. (2008) point out that Hoogwijk et al. assume crop production in the future to be 50% greater than is theoretically possible for rain-fed agriculture.

Table 3.4: **Overview of the IEA estimates of global potential of biomass for energy (EJ per year) until 2050 and some key assumptions**

Biomass category	Main assumptions and remarks	Energy potential in biomass up to 2050
Energy farming on current agricultural land	Potential land surplus: 0-4 Gha (average: 1-2 Gha). A large surplus requires structural adaptation towards more efficient agricultural production systems. When this is not feasible, the bioenergy potential could be reduced to zero. On average higher yields are likely because of better soil quality: 8-12 dry tonne/ha/yr* is assumed.	0 - 700 EJ (more average development: 100 - 300 EJ)
Biomass production on marginal lands	On a global scale a maximum land surface of 1.7Gha could be involved. Low productivity of 2-5 dry tonne/ha/yr.* The net supplies could be low due to poor economics or competition with food production.	< 60 - 110 EJ
Residues from agriculture	Potential depends on yield/product ratios and the total agricultural land area as well as type of production system. Extensive production systems require re-use of residues for maintaining soil fertility. Intensive systems allow for higher utilisation rates of residues.	15-70 EJ
Forest residues	The sustainable energy potential of the world's forest is unclear - some natural forests are protected. Low value: includes limitations with respect to logistics and strict standards for removal of forest material. High value: technical potential. Figures include processing residues.	30 - 150 EJ
Dung	Use of dried dung. Low estimate based on global current use. High estimate: technical potential. Utilisation (collection) in the longer term is uncertain.	5 - 55 EJ
Organic wastes	Estimate on basis of literature values. Strongly dependent on economic development, consumption and the use of bio-materials. Figures include the organic fraction of MSW and waste wood. Higher values possible by more intensive use of bio-materials.	5 - 50 EJ
Combined potential	Most pessimistic scenario: no land available for energy farming; only utilisation of residues. Most optimistic scenario: intensive agriculture concentrated on the better quality soils. In parentheses: average potential in a world aiming for large-scale deployment of bioenergy.	40 - 1100 EJ (200 - 400 EJ)

*Heating value: 19 GJ/tonne dry matter.

Sources: IEA 2007b after Berndes et al., 2003; Smeets et al., 2007; Hoogwijk et al., 2005a.

Table 3.5: **Bioenergy according to IEA reference scenario (2007a)**

	2005	2015	2030	2005-2015	2005-2030
Total primary energy supply - TPES (EJ)	479	601	742	26%	55%
Biomass and waste (EJ)	48	56	68	16%	41%
Share of biomass of TPES	10.10%	9.30%	9.10%	-8%	-9%
Total energy consumption - TEC (EJ)	324	404	497	25%	53%
Biofuels for transport (EJ)	0.8	2.4	4.3	200%	437%
Share of biomass of TEC	0.20%	0.60%	0.90%	140%	250%

Source: IEA 2007a / World Energy Outlook 2007.

In a detailed analysis of biofuels for transport, the OECD and FAO (2008) expect the global use of bioethanol and biodiesel to nearly double from 2005-2007 to 2017 (Table 3.6). Most of this increase will be due to biofuel use in the US, the EU, Brazil and China. But other countries not yet considered could also develop towards significant biofuel consumption. Indonesia, India, Australia, Canada, Thailand, the Philippines and Japan are all likely important producers and consumers in the foreseeable future.

The OECD and FAO (2008) also evaluated the role of feedstocks for the global production of biofuels until 2017 (Table 3.7) by taking policies in place in early 2008 into account and assuming them to be constant over the period to 2017. In total, biofuel feedstocks would increase from 50 Mt in 2005 to 193 Mt in 2017. As a result 9% of the global production of wheat and coarse grains plus oilseeds and vegetable oil would supply 5% of global gasoline and diesel demand with biofuels.

Table 3.6: Increase of biofuels use from 2005-07 to 2008 and projection to 2017

	Fuel ethanol plus biodiesel			
	2005-07 to 2008		2005-07 to 2017	
	PJ	%	PJ	%
Australia	26	323%	46	582%
Brazil	104	36%	435	150%
Canada	20	117%	63	371%
China	12	37%	98	297%
Columbia	9	156%	12	206%
Ethiopia	0.02	32%	0.83	1240%
EU Total	135	60%	520	231%
India	5	30%	20	137%
Indonesia	3	180%	71	4522%
Malaysia	2		5	
Mozambique	0.05	163%	0.54	1617%
Peru	0.04		0.04	
Philippines	1	259%	4	1010%
South Africa	0		8	
Tanzania	0.24	179%	1.44	1085%
Thailand	2	71%	26	925%
Turkey	0.32	35%	0.42	47%
USA	361	76%	759	160%
World Total	679	63%	2071	193%

Source: own compilation based on OECD/FAO 2008

Table 3.7: **Global demand and area for biofuels feedstocks until 2017 according to OECD/FAO (2008) projection**

	2005	2007	2017	2005 to 2007			2007 to 2017		
				absolute	%	% p.a.	absolute	%	
Wheat and coarse grains									
Total demand, Mt	1622	1702	1930	80	4.90%	2.50%	228	13.40%	1.30%
of which, biofuel Mt	46	93	172	47	102.20%	51.10%	79	84.90%	8.50%
of which: biofuels, %	2.80%	5.50%	8.90%						
Total production, Mt	1615	1661	1906	46	2.80%	1.40%	245	14.80%	1.50%
Area harvested, Mha	525	531	539	6	1.10%	0.60%	8	1.50%	0.20%
Yield, t/ha	3.08	3.13	3.536	0.05	1.70%	0.80%	0.41	13.00%	1.30%
Oilseeds and vegetable oil									
Total demand, Mt	96	105	143	9	9.40%	4.70%	38	36.20%	3.60%
of which, biofuel, Mt	4	9	21	5	125.00%	62.50%	12	133.30%	13.30%
of which: biofuels,%	4.20%	8.60%	14.70%						
Total production, Mt	99	106	143	7	7.10%	3.50%	37	34.90%	3.50%
Area harvested, Mha	145	142	164	- 3	- 2.10%	-1.00%	22	15.50%	1.50%
Yield, t/ha	0.68	0.75	0.872	0.06	9.30%	4.70%	0.13	16.80%	1.70%
Biofuel feedstocks total									
Total demand, Mt	1718	1807	2073	89	5.20%	2.60%	266	14.70%	1.50%
of which, biofuel, Mt	50	102	193	52	104.00%	52.00%	91	89.20%	8.90%
of which: biofuels,%	2.90%	5.60%	9.30%						

Source: own compilation after OECD/FAO 2008

3.2. Development of agricultural yields

Future development of global agricultural yields will determine the degree to which biomass demand for food and non-food biomass can be supplied from existing cultivated land. Furthermore, commodity prices will be significantly influenced by future yield developments.

Development of global agricultural yields will determine the degree to which biomass demand for food and non-food biomass can be supplied from existing cultivated land.

Data from the FAO show that relative yield increases in the last decades have in general weakened (Fig. 3.7; see also Hazell and Wood 2008 for cereal yields). Data from 1961 to 2005 show reduced average annual percent yield increases of six field crops (selection after Lobell and Field 2007). The decrease in yield changes was particularly strong for soybeans, an important crop for both food and feed and biofuels.

A higher potential for yield improvements is commonly seen for developing countries, especially for Africa. However, both the FAO (2006) and IFPRI (2001) assumed future yield increases[8] for cereals in developing countries of 1.0-1.1 % p.a. on average and 1.3% for roots and tubers (Table 3.8).

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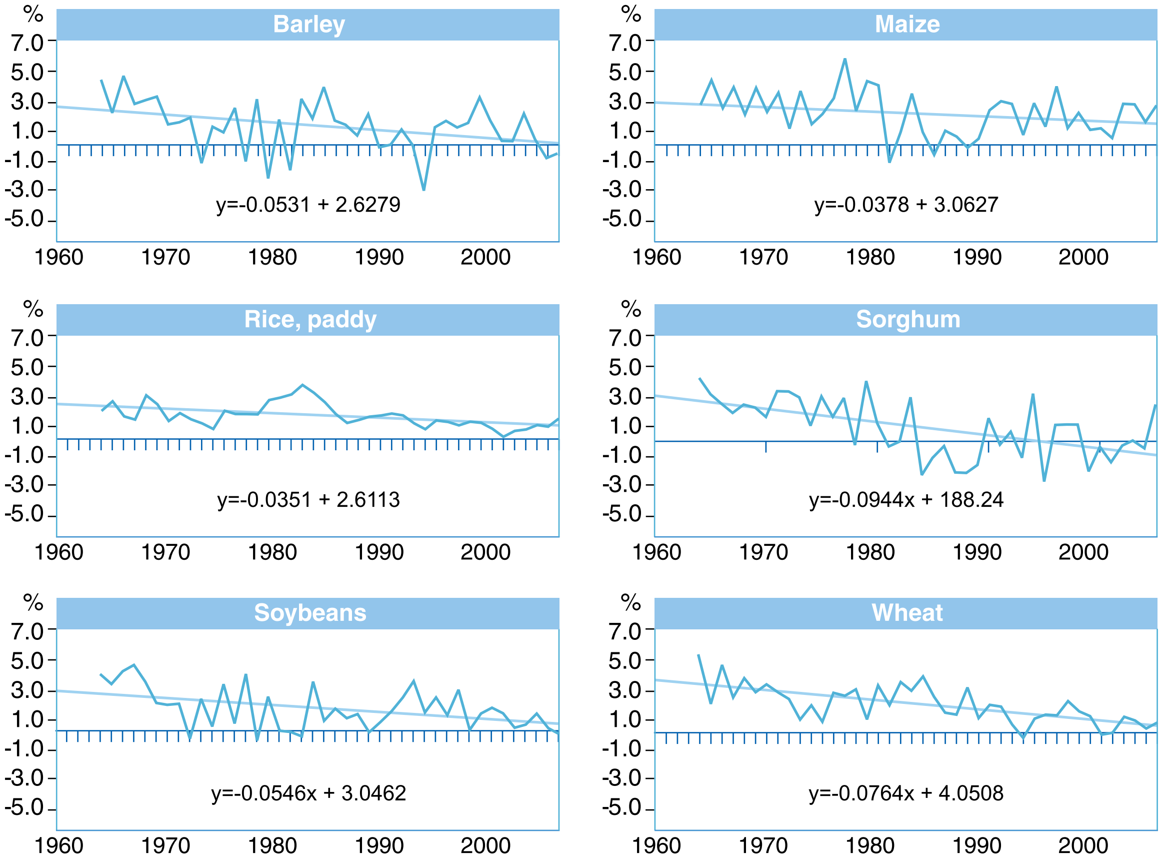
[8] In absolute terms the yield increase also declined significantly for wheat and sorghum but fluctuated around a rather constant level for the other crops; note: for mathematical reasons the growth rate of crop yield may decline when absolute yield increases or stays constant.

Figure 3.7: Change of global crop yields (in %) – 5 years moving averages



Note: t-statistic for regressions: Barley: -2,61**; Maize: -2,07**; Rice, paddy: -3,70***; Sorghum: -4,32***; Soybeans: -3,06***; Wheat: -5,82***
(*** and ** indicate significance at the 1 and 5% two-side confidence intervall, resp.).

Source: based on FAOSTAT online data 2008.

This expectation is in line with the OECD-FAO 2007 Agricultural Outlook and with OECD/IEA (2008). Even though more recent estimates of OECD/FAO (2008) come to somewhat higher average annual increases of yields, these rates of increase would still be below average rates of the past on a global level.

Several factors render the estimation of future crop yields rather uncertain. Among these are water availability, climate change, environmental restrictions, the evolution of agricultural markets, and negative yield shocks.

Scenarios from IFPRI (Rosegrant et al. 2002) show that under unfavourable conditions in the water sector (scenario "water crisis"), the global cereals yields would increase only by 0.9% p.a. between 1995 and 2025, compared to 1.2% for the BAU reference (Table 3.8). On the other hand, a favourable sustainable water supply worldwide would lead to increases of 1.3% p.a. between 1995 and 2025.

Factors such as water availability, climate change, and the evolution of agricultural markets make the development of future crop yields uncertain.

Table 3.8: Recent and projected development of yields

FAO 2006: World agriculture towards 2015 - 2030. Summary report. p. 10 Rome.*					
Developing countries					
	Yields (tonnes/ha)				
	1979-81	1997- 99	2015	2030	
All cereals	1.9	2.6	3.2	3.6	
	Yields increase (% per annum)				
	1979-81 to 1997-99	1997-99 to 2015	1997-99 to 2030	2015 to 2030	whole period
All cereals	2.0%	1.4%	1.2%	0.8%	1.8%
IFPRI 2001: Global Food Projections 2020					
	Yields (tonnes/ha)		yields increase		
	1997	2020	whole period	% per annum	
World					
Cereals	2.7	3.38	25.2%	1.1%	
Roots and tubers	12.96	16.82	29.8%	1.3%	
Developing countries					
Cereals	2.31	3.07	32.9%	1.4%	
Roots and tubers	11.78	16.12	36.8%	1.6%	
Industrial countries					
Cereals	3.38	3.97	17.5%	0.8%	
Roots and tubers	17.23	19.75	14.6%	0.6%	
Rosegrant et al. (IFPRI) 2002: World water and Food to 2025					
World: Cereals yields					
	t/ha	1995-2025	% per annum		
Baseline 1995	2.58				
BAU 2025	3.48	35%	1.2%		
Water Crisis 2025	3.26	26%	0.9%		
Sustainability 2025	3.58	39%	1.3%		
*for more details on crops see Table A8 in annex of FAO 2006.					

Source: own compilation based on different sources shown in Table.

Table 3.9: **Major crops used for the production of biofuels, main producing countries and the share of area under irrigation in 2000**

Crop	Main producing countries (both food and fuel)	Land under irrigation (%)
Sugar cane	Brazil / India / China / Thailand	14 / 80 / 28 / 64
Sugar beet	France / USA / Germany / Russia	15 / 53 / 5 /5
Cassava	Nigeria / Brazil / Thailand / Indonesia	0
Maize	USA / China / Brazil / Mexico	21 / 40 / 0 / 17
Oil palm	Malaysia / Indonesia / Nigeria / Thailand	0
Rapeseed	China / Canada / India / Germany	3 / 0 / 8 / 0
Soybean	USA / Brazil / Argentina / China	10 / 0 / 0 / 29

Note : The duration and frequency of irrigation may differ between and within countries: e.g. sugar cane in Brazil is irrigated only in most critical periods in the Center-West region and somewhat more frequently in the Northeast region (at planting and in periods of most critical growth)

Source: De Fraiture and Berndes (2009) after Müller 2008

Irrigation is already quite important for growing biofuel crops in many areas (Table 3.9). The expectation is that this will increase between 14% and 45% between 2000 and 2050, although we already live in a water-short world (de Fraiture and Berndes 2009).

Lobell and Field (2007) estimated that since 1981, global warming has resulted in annual combined losses of wheat, maize and barley of roughly 40 Mt or $5 billion per year as of 2002. The authors conclude that while these impacts are small relative to the technological yield gains over the same period, the results demonstrate that climate trends are already having negative impacts on crop yields at the global scale.

Lobell and Field (2007) also assume that maize and sorghum yields will decrease in response to warming, with an average of about 8% yield loss for each degree Celsius increase. The response of non-food crops to temperature increase is less well known, although one simulation study indicated that switchgrass yields in the Great Plains will increase by as much as 50% for 3.0–8.0 ˚C warming, because switchgrass experiences substantial cold temperature stress under current conditions. In the US, switchgrass might gain an advantage relative to most other crops as the climate warms. This represents a potential adaptation option for farmers who currently grow maize or sorghum. Carbon dioxide fertilisation effects on biomass energy crops such as maize and switchgrass will probably be small because they are relatively insensitive to rising atmospheric carbon dioxide.

Climate trends are already having negative impacts on crop yields at the global scale.

Climate change may also lead to a higher frequency of extreme weather events (IPCC 2007b). The FAO (2008) concludes that weather-related shocks to yields and to supply explain part of the recent commodity price increase, and such shocks may become more frequent in the future. With very low level of global grain stocks like in recent years, the implications of additional yield shocks may be even more pronounced. Although climate change may only slightly affect cereal yields on a global scale, it is expected to widen the gap between developed and developing countries, with reductions in production capacity of semi-arid developing countries such as sub-Saharan Africa being the most severe, accompanied by yield increases in northern developed regions, particularly in North America and Russia (Fischer et al. 2002; Fischer et al. 2005; Parry et al. 2004).

Trends in yield growth are relevant to the long-term evolution of agricultural markets and determine the ability of world agriculture to adjust to structural shifts such as the emergence of major new sources of demand. As pointed out by the FAO (2008), two opposing arguments can be made.

- Yield growth may be constrained, or even negative, in some regions due to climatic changes, possibly even leading to declining global yields. Moreover, weather-related yield shocks will become more common.
- Yield growth may accelerate if high crop prices are sustained, as investments in new technologies increase and more producers see profits from raising their own yields, possibly even leading to substantial yield growth in developing countries.

It seems unlikely that the high growth rates of average global agricultural yields over the past decades will be continued.

Overall, one may conclude that the further development of yields will be associated with a higher level of uncertainty compared to today. Nevertheless, it seems unlikely that the high growth rates of average global agricultural yields over the past decades will be continued. Relevant reference projections therefore plausibly assume a more moderate increase for the coming decades.

3.3. Increase and change of food demand

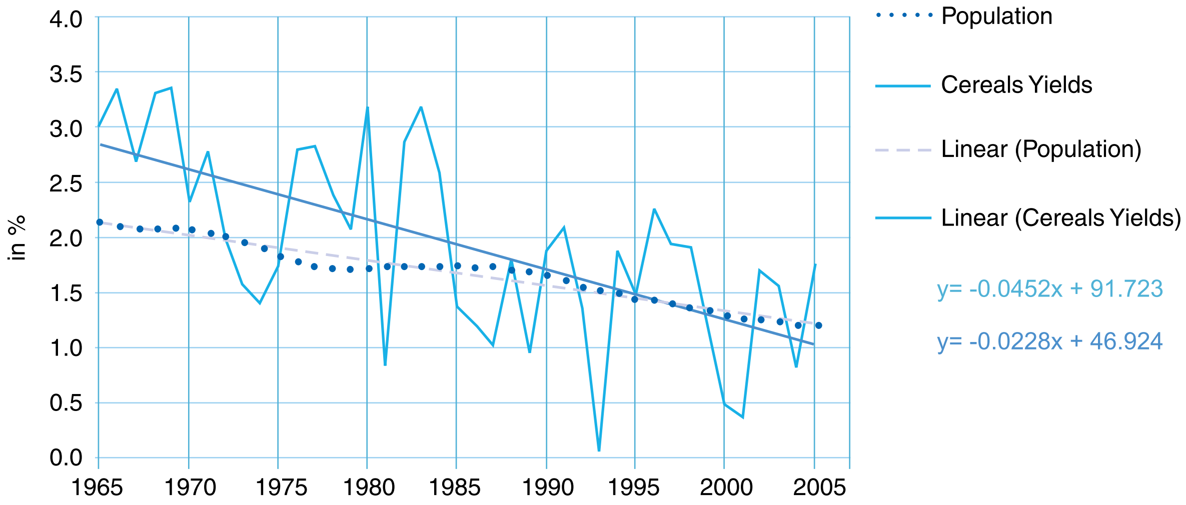
From 1965 until about 1995, the increase of cereal yields exceeded the growth rate of the human population (Fig. 3.8). As a consequence, the existing cropland was sufficient for food supply. Global population increased by 115% from 1960 to 2005, and the available agricultural area per person decreased by almost half over the same period (Fig. 3.9). Nevertheless, total food consumption per person on average increased by 25% due to efficiency improvements in agriculture that led to rising yields (see Section 3.2). Since the middle of the 1990s, however, population numbers have increased at about the same rate as average global yields. Perhaps worse, FAO (2008b) estimates that the number of malnourished people reached 963 million in 2008, an increase of some 40 million over 2007.
UN (2006) projects world population to increase from 6.1 billion in 2000 to ca. 8.3 billion in 2030 (plus 36%). Developing countries will contribute the most to this increase with their total population increasing from 4.7 to 6.9 billion over the same period (plus 45%). For the world average, overall population is predicted to grow about as fast as cereal yields (see Section 3.2).

Thus, if those predicted yield increases were not to materialise, this would significantly hamper world food supply. Moreover, any additional demand for biomass production – for food and non-food purposes – may only be supplied through an expansion of cropland at the expense of other land uses.

In fact, demand is already growing. Since the early 1990s, global consumption patterns began to change towards higher consumption of animal products while vegetal consumption of products stagnated (Fig. 3.9).

More recent analyses by the FAO (2008) show that from 2003–05 to 2007, production of beef, pork, poultry, sheep meat and milk increased, and many developing countries posted well over 10% growth. In contrast, EU meat production was stagnant and EU dairy production fell (Fig. 3.10). The increase of meat production in some key regions is expected to slow somewhat, but to remain strong in developing countries despite the lingering effects of higher feed costs (FAO 2008).

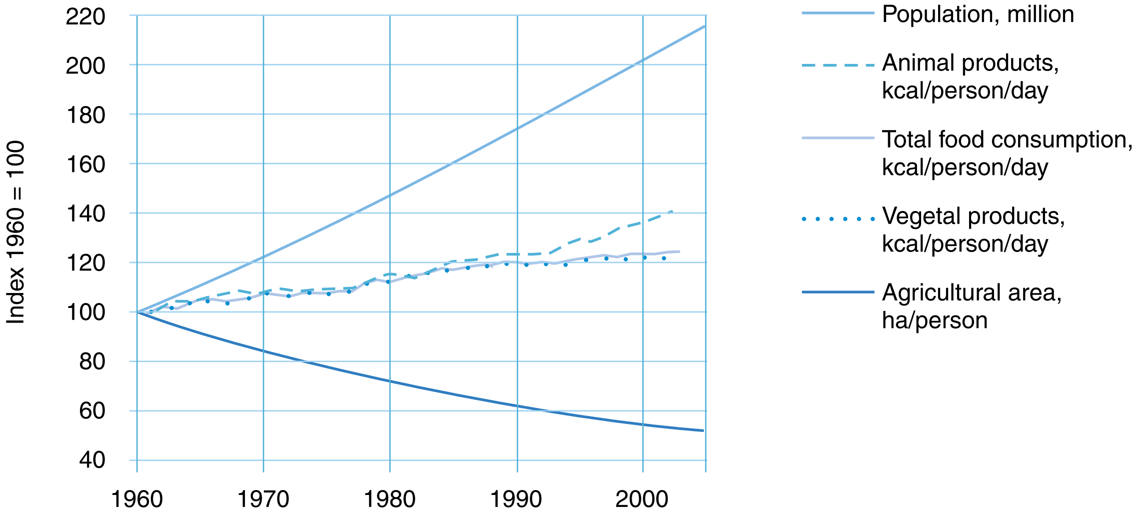
Figure 3.8: World population vs. cereal yields: growth rates as moving average over 5 year periods, 1961 to 2006



Note: t-statistic for regressions: Population: -28,55***; Cereals Yields: -5,12*** (*** indicates significance at the 1% two-side confidence level).

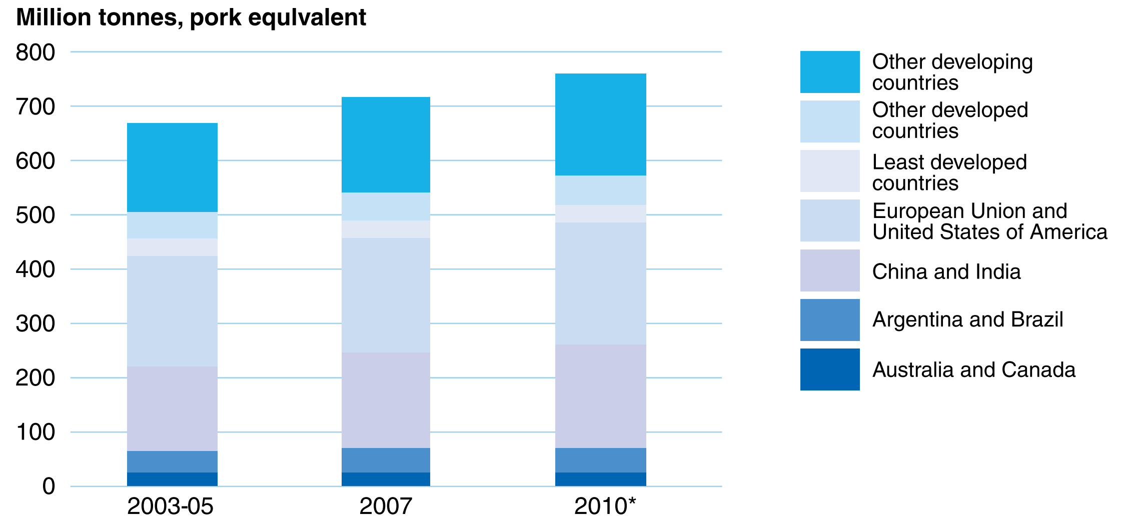
Sources: U.S. Census Bureau, International Data Base; FAOSTAT online for cereals yields.

Figure 3.9: Development of global population, agriculture land and consumption per person in the past (1960 - 2005)



Sources: UN population statistics online; FAOSTAT online

Figure 3.10: **Global production of selected livestock products 2003-05 to 2010**



Note: Selected livestocks products include beef, pork, poultry, sheep meat and milk
*Data for 2010 are projections

Source: OECD-FAO (2008)

Simply to feed the world population will require cropland to expand or yields to increase higher than expected. Any land requirements for energy and other non-food crops will necessarily add to this demand.

By 2030, the global meat consumption per capita is projected to increase by ca. 22%, milk & dairy by 11% and vegetable oils by 45% compared to the year 2000 (Table 3.10). This increase, driven by changing consumption patterns mainly in developing countries catching up with developed country patterns, means a doubling of the demand for these commodities in absolute terms. Also, the consumption of cereals, roots and tubers, sugar and pulses is expected to increase in developing countries above the world average, though at lower rates than the animal based commodities. Overall, the world population should be supplied with ca. 9% more food energy per capita in 2030 than in 2000, though with unequal distribution, the continuing problem of malnourishment in the midst of plenty remaining unacceptable on ethical grounds.

The projected increase of animal based diets points to an increasing demand for cropland. By 2020, changing diets and demand for biofuels are estimated to increase demand for cropland by 200-500 Mha, even taking into account anticipated improvement in yields (RFA 2008). This area would equal 12% to 31% of global cropland in 2020. For biofuels alone, RFA (2008) estimates 56 to 166 Mha cropland requirement in 2020, implying an increased demand of 144 to 334 Mha global cropland for changing diets in 2020.

Altogether, the world population might grow at a rate similar to expected average yield increases. However, consumption patterns in developing countries are likely to continue to change towards more meat and dairy, which requires significantly more crop and pasture land. Therefore, simply to feed the world population will require cropland to expand or yields to increase higher than expected. Any land requirements for energy and other non-food crops will necessarily add to this demand.

Table 3.10: **Consumption of food commodities 1999-2001 and projected in 2030, in the world and in developing countries**

World

	Consumption (Million tonnes)		Consumption (kg/capita)		Increase absolute		Increase per capita	
					%	% per annum	%	% per annum
	1999-2001	2030	1999-2001	2030	1999-2001 to 2030	1999-2001 to 2030	1999-2001 to 2030	1999-2001 to 2030
Cereals	1865	2677	307.2	323.7	43.5%	1.5%	5.4%	0.2%
Roots and tubes			69.4	75.0			8.1%	0.3%
Sugar			23.6	26.0			10.2%	0.3%
Pulses			5.9	6.0			1.7%	0.1%
Meat	228	378	37.6	45.7	65.8%	2.2%	21.7%	0.7%
Milk & Dairy	572	868	94.2	105.0	51.8%	1.7%	11.4%	0.4%
Vegetable oils	106	210	17.5	25.4	97.8%	3.3%	45.2%	1.5%
Total Food in kcal / person / day			2789	3040			9.0%	0.3%

Developing countries

	Consumption (Million tonnes)		Consumption (kg/capita)		Increase absolute		Increase per capita	
					%	% per annum	%	% per annum
	1999-2001	2030	1999-2001	2030	1999-2001 to 2030	1999-2001 to 2030	1999-2001 to 2030	1999-2001 to 2030
Cereals	1125	1799	237.8	261.9	59.9%	2.0%	10.1%	0.3%
Roots and tubes			67.0	75.0			11.9%	0.4%
Sugar			20.7	25.0			20.8%	0.7%
Pulses			6.7	7.0			4.5%	0.1%
Meat	127	258	26.7	37.5	103.7%	3.5%	40.3%	1.3%
Milk & Dairy	251	526	53.1	76.6	109.8%	3.7%	44.5%	1.5%
Vegetable oils	67	141	14.2	20.5	109.8%	3.7%	44.5%	1.5%
Total Food in kcal / person / day			2654	2960			11.5%	0.4%

Source: own compilation based on FAO (2006)

Section 4: **Life-cycle-wide environmental impacts of biofuels**

Biofuels are associated with various environmental impacts along the production-consumption chain (Fig. 4.1). Those impacts need to be attributed to different products, as biofuel production generally yields one or more co-products, like animal fodder or soymeal, or may be a co-product of some other, higher-valued process, like bagasse from sugar cane for heat or electricity production.

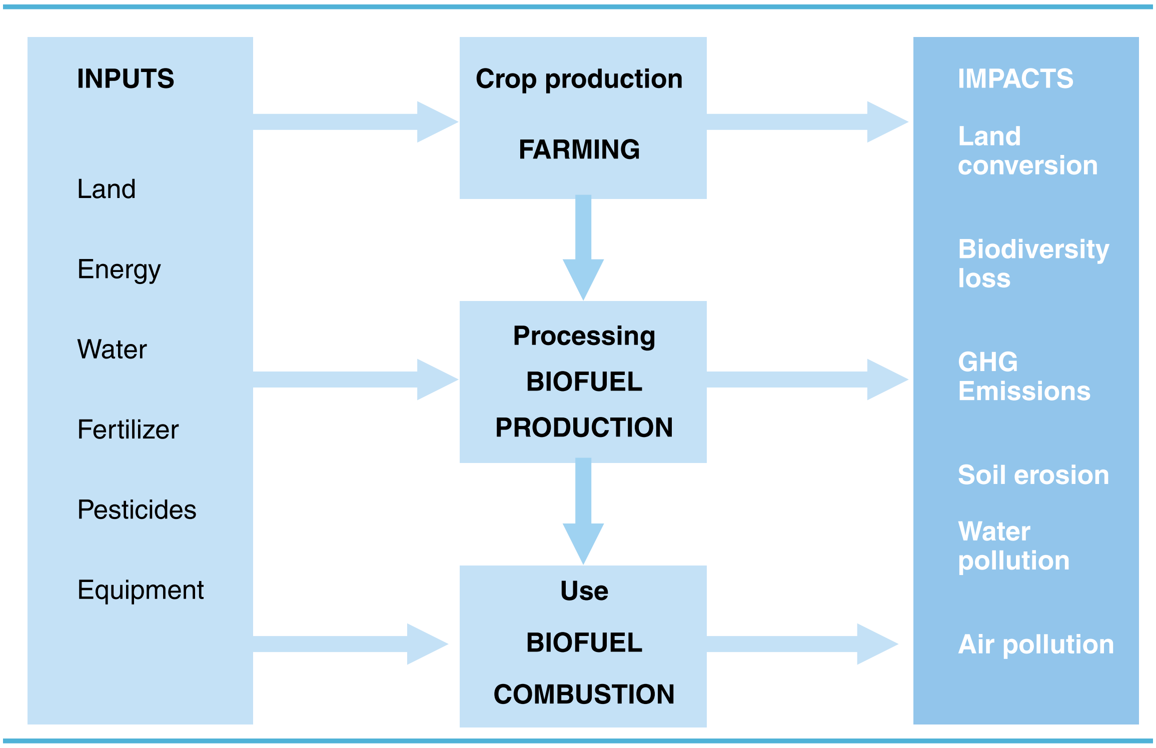
Life-cycle-wide impacts of biofuels are usually studied in a comparative manner, in order to analyse which alternative – amongst fossil or bio-based options – has the lesser environmental burden. Often, the alternatives have different strengths and weaknesses.

Moreover, the environmental impacts of biofuels are determined by the overall demand (Fig. 4.2). A growing demand for fuel crops may only be supplied through the expansion of cropland. Indirect impacts of biofuel production, like the destruction of natural habitats (e.g. rainforests or savannahs) to expand agricultural land, may have larger environmental impacts than the direct effects. In the worst cases, for example, the GHG emissions from biofuel production may be higher than from an equal amount of fossil fuels (Delucchi 2006; Farrell et al. 2006).

Biofuels may also change the geographical distribution of the environmental burden of feedstock production within a country or a region, across borders, and also from developed countries to developing countries. The extent to which the co-products of biofuel production displace other products and their environmental impacts (rather than stimulate additional consumption) depends on the elasticity of demand in the relevant markets (the more inelastic the demand, the greater the substitution), the way in which the co-products affect supply curves, and other market and non-market (i.e. political and regulatory) factors.

Biofuels are associated with various environmental impacts along the production-consumption chain. Growth in overall demand can exacerbate these impacts.

Figure 4.1: General biofuel pathway with inputs and environmental impacts



Source: this report

Life-cycle oriented assessments need to consider both the production chain and the spatial perspective at various scales.

As a consequence, two basic approaches need to be considered with life-cycle oriented assessments:

a. the product and project based perspective ("vertical analysis"), and
b. the regional, national and global perspective ("horizontal analysis").

In this section we will start with the first approach, and section 5 will extend the perspective with the second approach.

4.1. The greenhouse gas balances of biofuels

The GHG balance of biomass production depends on the fossil fuel inputs used during cultivation, the amount of fossil fuels replaced by produced biofuels, and GHG released due to clearing of areas with high carbon storage value.

Greenhouse gas emissions and energy requirements of biofuel production vary widely, depending on the feedstock, technology considered and boundary conditions assumed.

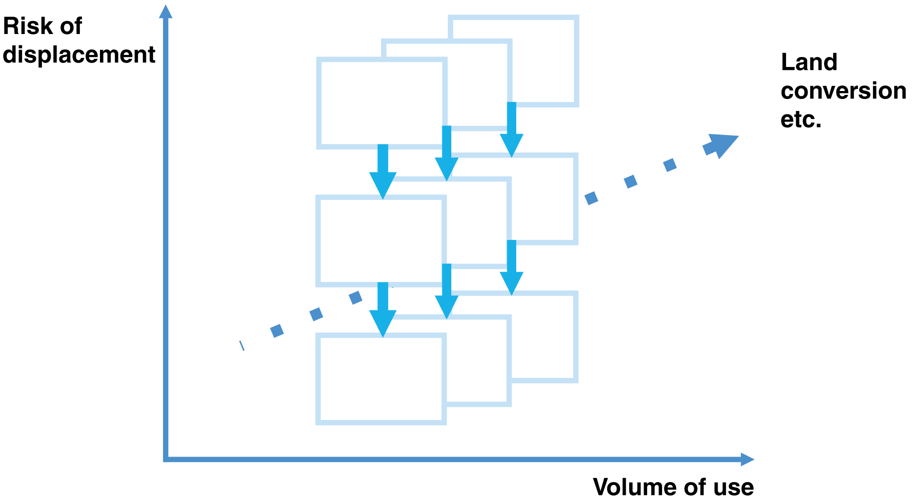
Zah et al. (2007) provide an overview of the distribution of GHG emissions along different production chains for bioethanol, biodiesel, methanol, and methane used for transport (see Fig. A.1 in the appendix). Depending on the biofuel type and production pathway studied, they observed net GHG savings of up to 80% compared to fossil fuels. Along the production chain, the processes contribute differently to the overall performance.

According to Zah et al. (2007), the GHG balance of biomass production depends on the fossil fuel inputs needed in cultivation (machinery, fertilisers, pesticides) and the amount of fossil fuels replaced by produced biofuels. This balance varies significantly between different plants, because their area yields and input requirements are very different. N_2O emissions from agricultural fields may also contribute substantially to GHG emissions. Regional differences in the intensity of clearing of rainforest or other areas with high carbon storage value can have a significant influence on the total balance.

In contrast to agricultural production, the provision of waste materials and residuals do not require significant energy input. Therefore, the lowest GHG emissions are achieved using biodiesel from waste vegetable oil from nutrition or methane from manure.

The production process of the fuels contributes, on average, much lower GHG emissions than the agricultural cultivation. Particularly low are emissions from oil extraction and transesterification to biodiesel. Emissions from the fermentation of bioethanol are variable: emissions are high when fossil energy carriers are used (as is often the case with bioethanol from corn); they are low when wastes from production are used to generate process energy (bagasse from sugar cane processing in Brazil thus becomes a co-product). The highest GHG emissions result from methane and N_2O during subsequent fermentation of the residuals as well as methane escaping during the preparation of biogas. A large

Figure 4.2: The impacts are depending on the overall demand



Source: this report

part of the methane emissions can, however, be prevented, for example by performing the fermentation in sealed containers.

The transport of fuels from production sites to fuel stations in most cases causes significantly less than 10% of total emissions as long as inter-continental transport occurs by tankers or pipelines. The use phase of biofuel-driven vehicles is CO_2-neutral because the CO_2 emitted has been fixed by plant growth in a short time period. The emissions due to supply and maintenance of vehicles and roads do not depend on the fuel, but they can provide a major contribution to the overall emissions in cases of even highly efficient biofuels.

Menichetti and Otto (2008) reviewed existing LCA-studies. Most of the available studies focussed on GHG emissions, considering different biofuel production pathways according to biofuel type, feedstock type, geographical scope and conversion technology process, and on biofuels for transportation. Figure 4.3 also includes data for biomethane from manure, bioethanol from agricultural or forestry residues and Fischer-Tropsch diesel from wood, based on RFA (2008).

Among the four main feedstocks for production of bioethanol, corn is the only one that may cause 5% more GHG emissions than fossil fuels, but may also bring benefits of about 60% GHG emissions saved - depending on the technology used, the process energy mix, and the use of co-generation products, but excluding the effects of land use change. According to Wang et al. (2007) the ethanol performance in terms of GHG emissions ranges from slightly negative values to significant improvements depending on the type of technology used in the milling plant, the state-of-the-art of the milling plants, the process fuel used (natural gas, coal or renewables), the use of co-generation, and the fate of distiller grains and solubles. Furthermore, when lower and upper limits of error bars within the individual studies are also taken into account, the range for bioethanol from corn ranges from minus 47% to plus 58% GHG emissions relative to fossil gasoline. Recently, Liska et al. (2009), considering latest state-of-the-art US technology, recorded plus 48% to 59% GHG savings of corn ethanol, about two- to three-fold more than many earlier studies[9].

Bioethanol from sugar cane shows the highest potential for GHG savings of the four bioethanol types studied. Higher values (beyond 100%) are due to co-products. This reflects the recent trend in Brazilian industry towards more integrated concepts combining the production of ethanol with other non-energy products and selling surplus electricity to the grid.

In contrast to agricultural production, the provision of waste materials and residuals do not require significant energy input.

Among the four types of feedstocks studied for biodiesel production, soy beans and palm oil may, under certain circumstances, produce higher GHG emissions than fossil diesel. This is the case when natural vegetation was converted to cropland for soy cultivation in Brazil (Zah et al. 2007). Palm oil biodiesel production may on the one hand result in a quite significant improvement in GHG emissions compared to conventional diesel. On the other hand, if areas that were not previously cultivated are converted to palm oil production, the net resulting balance can be dramatically negative. Beer et al. (2007) compare a base case scenario from cropland with palm oil from cleared rainforest and cleared peat forest. Results change from 80% improvement to over -800% if land use change is from rainforest and -2000% if land use change is from peat forest, due to the mobilisation of the carbon stocked in the vegetation and the soil (Fig. 4.3).

Some biofuels have GHG savings greater than 100% due to the co-generation of products. In the case of biomethane from manure, using feedstocks from waste may result in net GHG benefits of up to 174%, whereas especially methane escaping from biogas plants may lower the overall performance to only 37% GHG savings.

A particularly high GHG savings effect may be achieved for second-generation bioethanol from agricultural or forestry residues and FT diesel from wood. These technologies are still in the R&D stage, so results for large scale production are not yet available.

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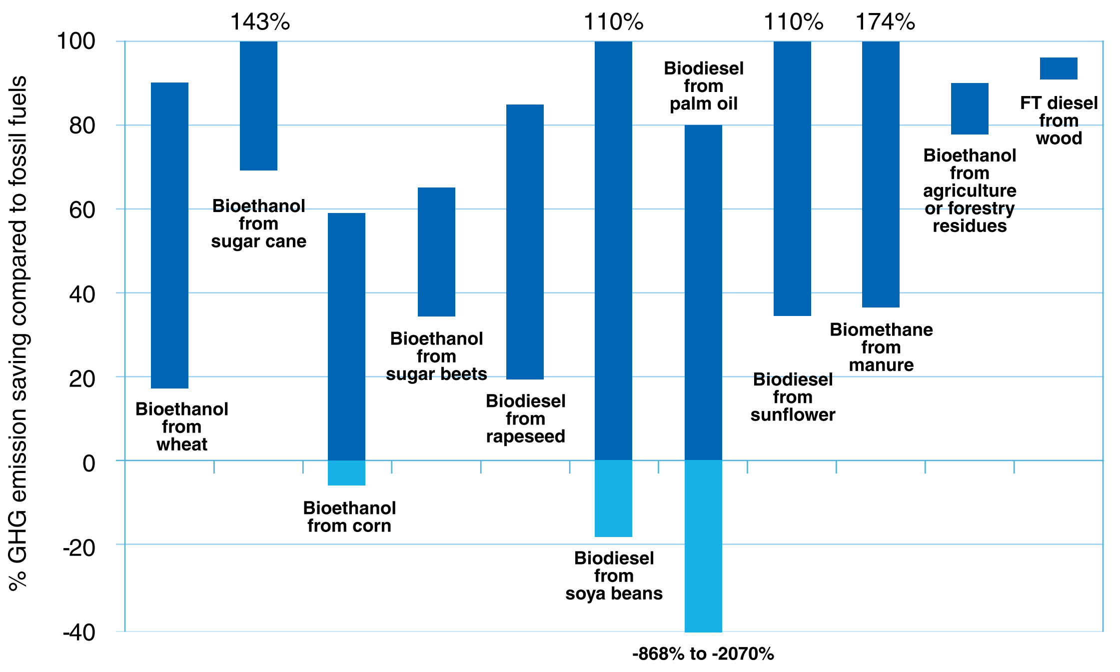
[9] The highest value is recorded with 67% for an integrated biorefinery, but this value is debatable as the biogas from the manure from cattle is completely allocated to the ethanol production. The study uses 1.8% N_2O emission on average which results in about 25% of the life-cycle-wide GHG emissions, so that the results should be taken with care (see 4.3.1).

Figure 4.3: Greenhouse gas savings of biofuels compared to fossil fuels



Sources: own compilation based on data from Menichetti/Otto 2008 for bioethanol and biodiesel, IFEU (2007) for sugar cane ethanol, and Liska et al. (2009) for corn ethanol; RFA 2008 for biomethane, bioethanol from residues and FT diesel

While existing LCAs of different feedstocks and pathways indicate GHG improvements, results depend on whether co-products and land conversion are accounted for.

Reinhardt et al. (2008) also found high variability of the LCA results with regard to energy and greenhouse gas balances of biofuels. They investigated more than 800 studies for a comparative analysis of energy and GHG effects of 10 biofuel types, comprising in total 31 feedstocks versus their fossil fuel counterpart, and normalised the results to one hectare of land used. The energy and greenhouse gas balances of the biofuels considered were mostly favourable as compared to fossil fuels, if no land use change is involved (Fig. 4.4). However, because of competition for land and in the use of biomass, the potentials for energy crops are limited. They concluded that not all biofuels for transportation can be regarded as being sustainable: some of them are too costly compared to alternatives, and some carry negative environmental side effects, such as the destruction of ecosystems with high biodiversity. Geographically specific advantages play an important role. For example, bioethanol production from sugar cane is limited to (sub-)tropical climatic conditions while sugar beets in the temperate regions can only be cultivated on particularly fertile soils.

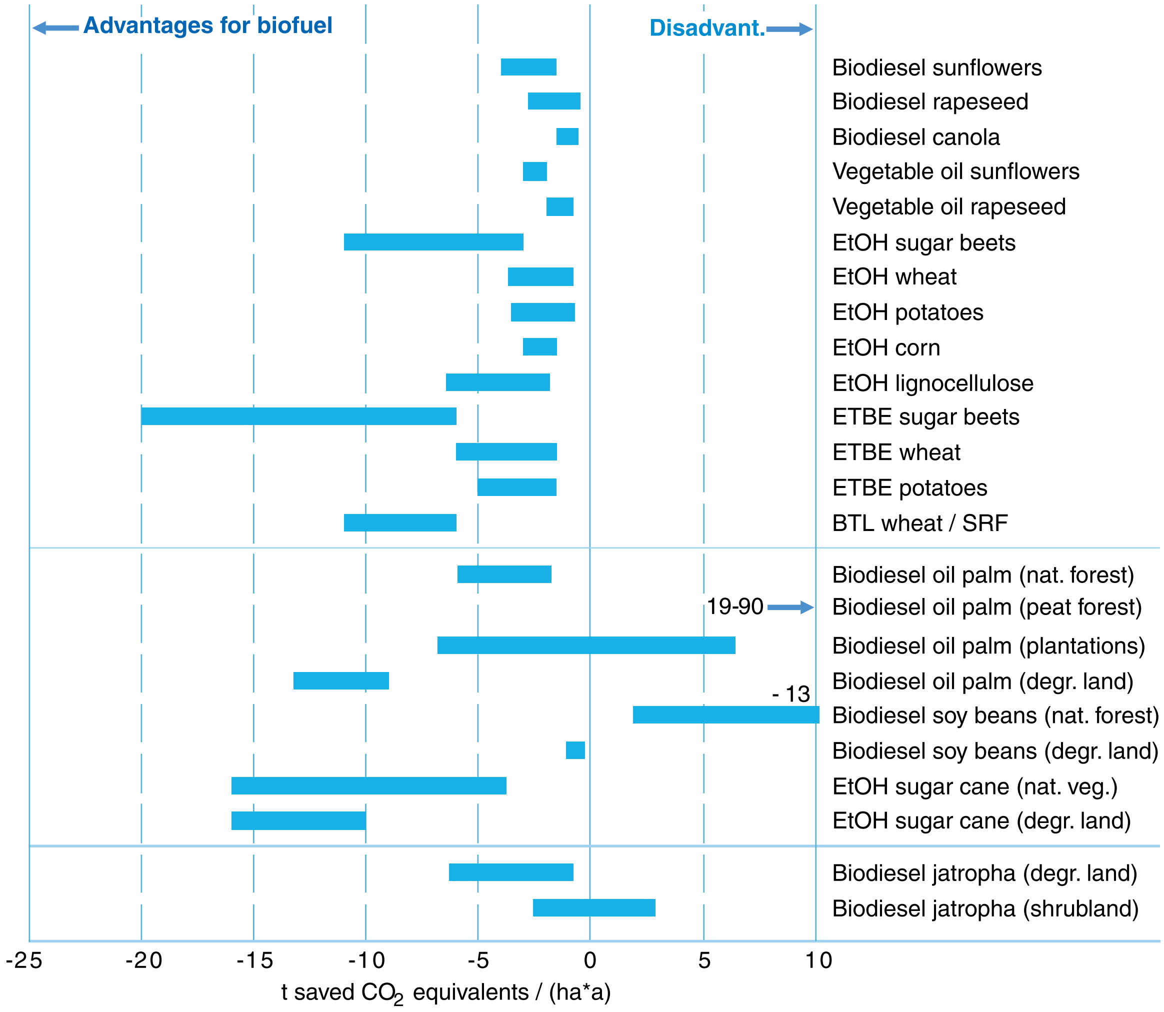
The high level of variability arises from different system boundaries and assumptions, e.g. those related to the cultivation, conversion or valuation of the co-products. As a result, a direct comparison between the different biofuel options is not always possible.

The results also depend critically on the way impacts of land conversion are attributed. The positive effect of biodiesel from palm oil on natural forest area only occurs if a depreciation period of 100 years for the GHG emissions resulting from land conversion is assumed (Fig. 4.5). Observations from Southeast Asia, however, indicate that palm oil plantations are often used for a period of only about 25 years (IFEU et al. 2007).

Yet, a positive GHG balance usually results when oil palm plantations are established on abandoned land, here also addressed as tropical fallow.

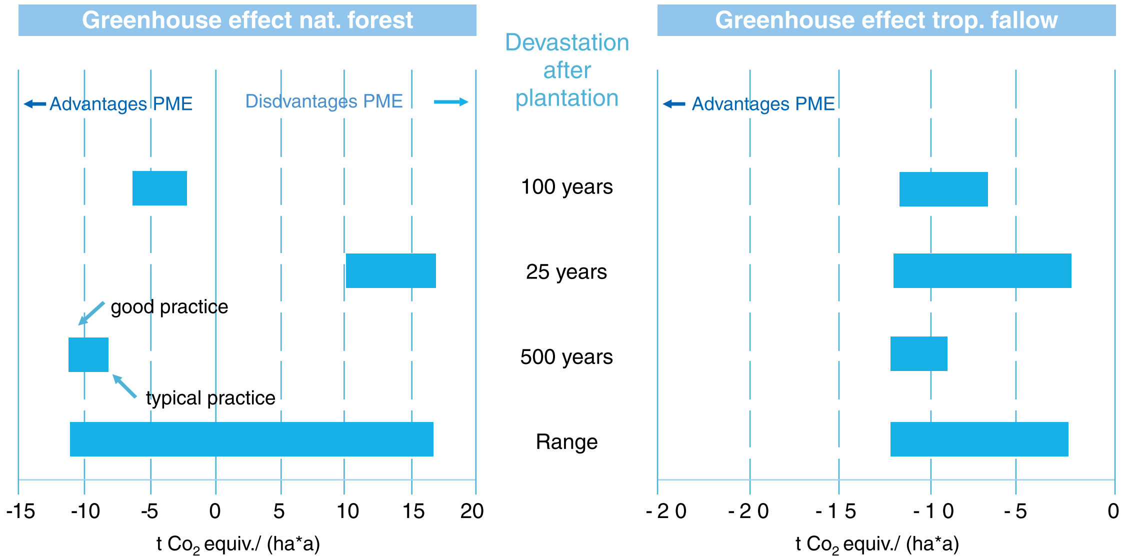
Overall, the GHG balance of biofuels for transport depends on several factors. Especially the co-generation of other products may lead to improved performance, whereas intensive agricultural production and conversion of natural land to cropland may lead to negative results. Energy generation from biomass waste and residuals outcompetes energy crops grown on agricultural land. Second-generation biofuels also show positive results if produced from waste or residues or from wood, but their applicability in large scale production remains to be demonstrated.

Figure 4.4: **Advantages and disadvantages for greenhouse gases for biofuels from agriculture compared to their fossil counterpart per hectare of cropland**



Source: Reinhardt et al. 2008

Figure 4.5: Effects of different depreciation periods (25 to 500 years) on GHG savings of biodiesel from palm oil for the conversion of natural forest and abandoned or fallow land



Note: PME stands for palm oil methyl ester

Source: IFEU et al. 2007

4.2. Impacts on water and other insufficiently covered impacts

Energy derived from biomass requires about 70 to 400 times more water than that derived from other energy carriers such as fossil fuels, wind, and solar.

Besides GHG emissions, other impacts such as eutrophication and acidification also need be considered in the comparison with fossil substitutes. However, in their review of LCA-studies Menichetti and Otto (2008) found only seven reports comparing results for a minimum of five impact category indicators. Less than one-third of the studies reviewed presented results for acidification and eutrophication, only six assessed the toxicity potential (human toxicity and/or eco-toxicity), seven included summer smog, four ozone depletion and three abiotic resource depletion potential. Water consumption was hardly ever mentioned.

If today's food production and environmental trends continue, a water crisis will emerge in many parts of the world. Biofuels may increase demands on this already pressured resource.

Zah et al. (2007) compared the net effects of GHG emissions of biofuels against cumulated non-renewable energy requirements, summer smog potential, eco-toxicity and eutrophication potential (Fig. 4.6). The best results (>50 % savings) were achieved with manure as a feedstock, biodiesel from waste oil, methanol, and methane from wood, as well as bioethanol from grass, wood, sugar beets and whey (Switzerland), sugar cane from Brazil, and sorghum from China. Nine biofuels (of which four were from waste materials) resulted in GHG savings of more than 30%, among which were biodiesel from different agricultural feedstocks and methane from different waste materials. In the extreme case of biodiesel from soy in Brazil, emissions were slightly higher than for fossil fuel. For the other environmental indicators, the ranking is quite different.

Summer smog potential is particularly high for the tropical biofuels because cropland is often supplied by slash-and-burn or dry leaves are burnt before harvesting.

Energy derived from biomass requires about 70 to 400 times more water than that derived from other energy carriers such as fossil fuels, wind, and solar (Gerbens-Leenes et al. 2008)[10]. More than 90% of the water required is used in the production of the feedstock. This is in line with the water demands of agriculture overall: 70% of all water diversions for human purposes are to irrigate crops (20% of crops worldwide, whereas 80% are rainfed) (De Fraiture & Berndes 2009). Roughly 45 billion cubic meters of irrigation water were used for biofuels production in 2007, or some 6 times more water than used for drinking water globally (Howarth et al. 2009).

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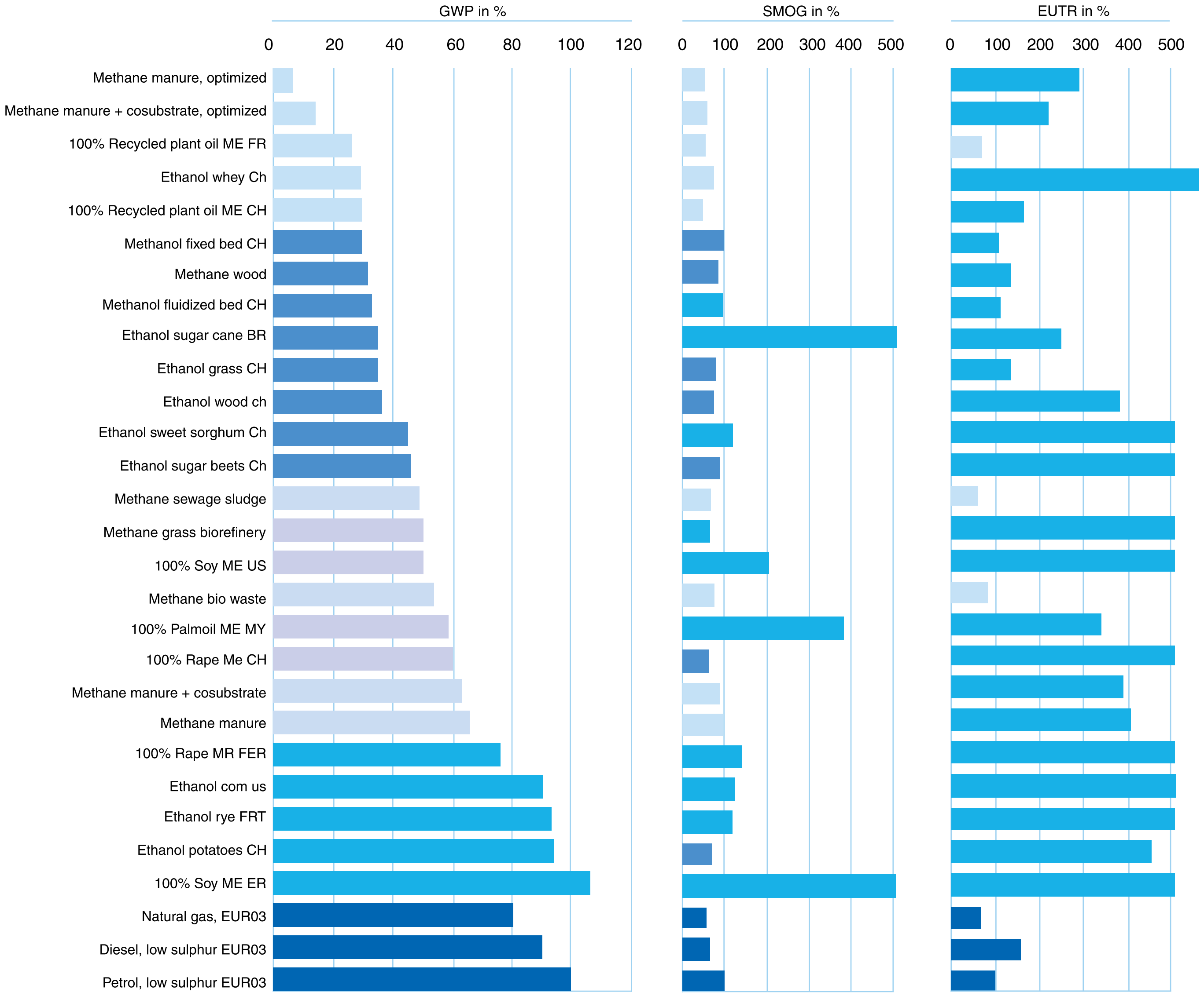
[10] Gerbens-Leenes et al. (2008) estimate the averaged water requirements for fossil energy at ~ 1 cubic meter evapotranspiration per gigajoule of energy (m^3 GJ^1) in comparison to the 24 - 146 m^3 GJ^1 reported for bio-energy.

Still, the total water requirement of transport biofuels from food crops (sugar cane, maize, and rapeseed) is modest compared to that of food production. About 1.4% of total food crop evapotranspiration and about 1.7% of total irrigation withdrawals are for biofuels (De Fraiture et al. 2008). However, a recent assessment on water management in agriculture (CA 2007) concluded that if today's food production and environmental trends continue, a water crisis will emerge in many parts of the world. Biofuels, especially of the first generation, may increase demands on this already pressured resource.

Figure 4.6: Life-cycle impact assessment of biofuels compared to fossil fuels for different environmental pressures



GWP: global warming potential, SMOG: summer smog potential, EUTR: excessive fertilizer use
Reference (= 100%) is petrol EURO3 in each case. Biofuels are shown in diagram at left ranked by their respective GHG emission reductions.
▢ ■ Fuels that have a total GHG emission reduction of more than 50% as versus petrol.
■ Those with GHG emissions reductions of more than 30%.
■ Those with GHG emissions reductions of less than 30%.
■ Production paths from waste materials or residue.
In other diagrams:
▢ ■ Better than reference.
■ Worse than reference.
■ Production paths from waste materials or residue.

Biofuel production can have serious implications for water quality, e.g through increased eutrophication.

Many biofuels show both advantages and disadvantages depending on impact categories assessed. When making the choice for a particular fuel and pathway, these trade offs need to be considered.

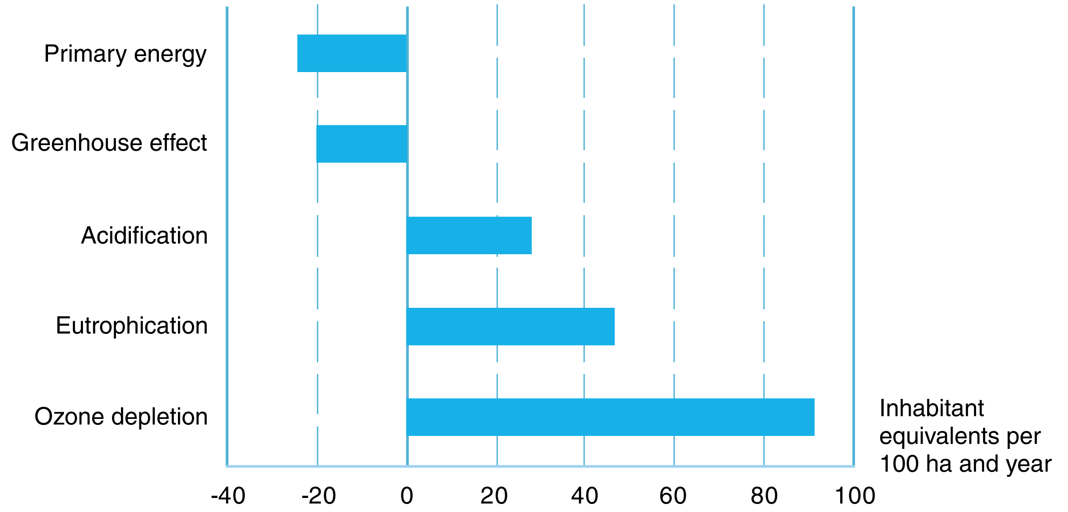
Increased eutrophication has been linked to biofuel production from agricultural crops, when compared with fossil fuels. Several recent studies demonstrate that ethanol production from grain and sugar crops can have serious implications for water quality (Simpson et al. 2008, 2009; Donner & Kucharik 2008; EPA/SAB 2008). Expanded corn acreage together with increased fertiliser application rates let N and P losses to watercourses rise. In the Northern Gulf of Mexico and Atlantic coastal waters, indications of increased eutrophication have been observed since the late 1970s and particularly since the early 1990s. The increased production of corn for ethanol is very likely to aggravate this problem (Simpson et al. 2008; Donner & Kucharik 2008). In fact, an advisory panel to the US government recently concluded that the increased production of corn-ethanol in the US may make it impossible to meet national targets to reduce the size of the Gulf "dead zone" (EPA/SAB 2008). Furthermore, the harvest of corn stover for cellulosic ethanol production would likely increase erosion (sedimentation) as well as nutrient losses.

These observations indicate that numerous impacts of biofuels are relevant, so life-cycle assessments need to account for the environmental impacts resulting from the combined effects of increased biomass production (see EEA 2008c).

The lack of LCA-studies focusing on a wider set of environmental impact indicators makes it difficult to assess trade-offs between different environmental impact indicators. Since many biofuels show disadvantages in some environmental impact categories (see Fig. 4.7 for the example of rapeseed biodiesel which shows advantages for primary energy and the greenhouse effect but disadvantages in terms of acidification, eutrophication and ozone depletion), any decision in favor of one or another fuel requires careful consideration.

The integrated assessment of different environmental impacts requires valuations and priority setting. The primary motivation for political promotion of biofuels was energy security and mitigation of greenhouse gas emissions. Therefore, one may argue that of the environmental impacts, GHG emissions and related land use change are the most important. GHG emissions should not, however, be reduced at the cost of other environmental pressures (incl. those on biodiversity and water).

Figure 4.7: **Environmental impacts of biodiesel from rape seed compared to conventional diesel fuel**



Source: Reinhardt et al. 2008.

4.3. Methodological constraints influencing results

Crop cultivation and the fuel production process account for the vast majority of total impacts over the life-cycle of bioenergy products. The distribution of impacts within these two phases varies between LCA-studies and depends largely on both the type of feedstock and the impact indicator considered.

Agriculture is responsible for a significant share of GHG emissions, and is a very large contributor to acidification and eutrophication. Much of this is associated with acceleration of the nitrogen cycle through the use of synthetic nitrogen fertiliser. This results in the release of the greenhouse gas nitrous oxide (N_2O) both in agricultural fields and in downstream aquatic ecosystems, which receive nitrogen runoff from the fields. This runoff is also the direct cause of eutrophication, and emissions of nitrogen gases such as NO_x and ammonia to the atmosphere contribute to acid rain.

Cross-cutting aspects affecting LCA results are the life-cycle inventory databases used for modelling upstream processes and the life-cycle impact assessment indicators methodology applied. The review of Menichetti and Otto (2008) showed that updated and scientifically acknowledged databases co-exist with somewhat older ones. The authors also analysed the main background assumptions of the studies. Two main factors were behind the discrepancies observed: the methodology followed for assessing N_2O emissions from fertilisers and the treatment of co-products in the technology conversion phase (Table 4.1).

4.3.1. Uncertainty about N_2O emissions

N_2O emissions are particularly relevant for crop-based biofuels because of their high contribution to global warming; 1kg of N_2O is equivalent to 298 kg of CO_2 emissions over a time horizon of 100 years (Solomon et al. 2007), so even small changes in the N_2O emissions can significantly affect the overall GHG balance for biofuels.

Because the use of fertilisers and related N balance and N_2O emissions are very site-specific, it is difficult to define representative average emission factors. Many LCA studies used the IPCC methodology for estimating N_2O fluxes, which tends to give estimates only somewhat over 1% of the N applied by fertiliser[11].

Table 4.1: **Identification of the main areas of converge and divergence in the background assumptions, for a selected number of studies**

Agricultural phase				Conversion phase		
Land use reference scenario	Crop yield	Amount of fertilisers	N balance	Allocation	Energy fuel used	Co-products allocation
▒	▒	░	█	░	▒	█

The colour codes should be read as follows:

▒ Quite consistent background assumptions, no area of concern

░ Some discrepancies observed in results, affecting results to some extent

█ High inconsistency area, affecting the results significantly

Source: Menichetti/Otto 2008

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[11] IPCC (2006) has changed default values compared to 2000: Emission Factor (EF) 1 (direct emissions of synthetic N to N_2O): 1% (down from 1.25% in 2000 guidelines), EF4 (indirect emissions from atmospheric N deposition) 1% (unchanged), EF5 (indirect emissions from leaching/runoff N): 0.75% (down from 2.5% in 2000 guidelines); example calculation: for the USA as a whole, 20% of the N applied to agricultural fields leaves in surface and groundwaters, and slightly over 10% is volatilised to the atmosphere (Howarth et al. 2002), which according to IPCC default values results in N_2O emissions via atmospheric deposition of 0.1% and via leaching of 0.15%; thus the indirect emissions of about 0.25% would not significantly add to the direct emissions of 1%.

If recent findings on N_2O emissions to the atmosphere are corroborated most LCA studies on biofuels would have to be reconsidered.

More recently, however, Crutzen et al. (2008), based on the observed global increase of N_2O in the atmosphere, found that the total emissions from fertiliser use must be more in the range of 3-5% on average compared to the 1% derived from the default values[12] of the IPCC approach. The difference could possibly be explained by denitrification processes occurring in the water and sediment downstream of the fields where the fertiliser has been applied, an argument supported by Howarth and Bringezu (2009). If these observations are corroborated, the results of most LCA studies performed on biofuels so far would have to be reconsidered.

4.3.2. Consideration of co-products and allocation methods

Different allocation methods lead to different results; the choice of the applied allocation method should be made transparent.

Menichetti and Otto (2008) also highlighted that different allocation methods have been applied in the reviewed studies (Table 4.2). Input energy and material flows and output emissions are allocated to the product and co-product(s) (ISO 14044 2006; Veeraraghavan & Riera-Palou 2006; Kodera 2007). Menichetti and Otto (2008) found that all methods have advantages and drawbacks. For example, system expansion, the option preferred by ISO, requires knowledge about the substituted product, as it implicitly assumes that co-products are sold on the market. Economic allocation reflects more properly the actual market conditions, but it also significantly increases the volatility of results and therefore their uncertainty. Ideally, this approach would require re-iteration of the LCA several times and adjusting the results accordingly.

For regulatory purposes involving the assessment of biofuels, energy allocation has been suggested as a more pragmatic approach. Depending on the use of co-products, this gives comparable results to those of the substitution method[13] (Hodson 2008). Both the European Directive on Renewable Energy (EU 2009b)[14] and the draft for the German Sustainable Biofuels Ordinance (Fehrenbach 2008) apply the energy allocation method. The UK Renewable Transport Fuel Obligation uses a mixed allocation method instead (Chalmers 2008).

Energy allocation may not be the best approach when products are used for their material properties, in particular when cascading use of biomass should be assessed (see section 6.5).

In any case, the choice of the applied allocation method should be made transparent and clearly discussed. Moreover, LCA studies should include sensitivity analysis of the different methods used.

4.3.3. Other constraints

Most LCA studies only include impacts on energy consumption and GHG emissions (EEA 2008c). As far as the former is concerned, some studies report only fossil energy consumption, others take into account total primary energy consumption (renewable and non renewable) thus not allowing an immediate comparison. Some studies use the net calorific value (e.g. Edwards et al. 2007 and Choudhury et al. 2002), some others the gross calorific value, and some both (e.g. Elsayed 2003).

Table 4.2: Allocation methods applied in the reviewed studies

Sub-division	System expansion	Allocation based on physical criteria		Allocation based on other criteria	Mixed methods	No allocation to co-products	Not applicable / Not available
		Mass-based allocation	Energy content-based allocation	Economic allocation			
1	12	0	1	3	6	1	6

Source: Menichetti/Otto 2008

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[12] Reflecting uncertainty, the upper range value of the IPCC (2006) for direct emissions is 3%, and 5% for EF4, and 2.5% for EF5, which for the USA example would result in 4% total N_2O emissions.

[13] Similar results are obtained when co-products are used for energetic purposes; when used for feed, energy allocation may render much more favourable results than substitution (de Dominicis, pers. comm. 1 July 2009)

[14] For the purpose of policy analysis the Renewable Energy Directive regards also the use of the substitution method as appropriate (paragraph 81 in EU 2009b).

With respect to global warming potential, most studies only take into account the contribution of CO_2, N_2O and CH_4. The IPCC method for calculating global warming potential actually includes a list of over 60 gases, some of which have a global warming potential over 10,000 times higher than CO_2. Delucchi (2006) calculated that the impact of taking into account other "indirect" GHGs, for example NO_x and ozone would change GHG emissions by 3 to 5% relative to an accounting that considers only CO_2, N_2O and CH_4.

4.3.4. Overcoming deficiencies of the LCA approach

LCAs are already used today in regulatory proposals to set environmental criteria and standards on biofuels. Menichetti and Otto (2008) have called for harmonised rules for LCA, particularly for a common set of impact indicators. Harmonised rules on how to carry out LCAs on biofuels would be based on reasonable guidelines and assumptions on methodological issues and how to deal with the associated uncertainty of key parameters. Initiatives to enhance harmonisation include the UNEP Life Cycle Initiative, the European Platform for LCA, and the international network GEDnet.

Like any method, LCA requires further development. This should include water-consumption and pollution issues, drawing for instance, on the Water Protocol of the Global Reporting Initiative or the work of EurepGAP.

LCA provides an indicative comparative assessment of biofuels with respect to GHG emissions and other environmental impact indicators, such as acidification, eutrophication, summer smog and toxicity. However, LCA aggregates results over time and space. It needs to be complemented by other environmental assessment tools looking at the dynamics of the various impacts in the spatial dimension, differentiating the regions where the environment is actually affected.

Land conversion is an important factor for determining the performance of biofuels, but LCA has limited capability to assess environmental impacts resulting from indirect land use change. Menichetti and Otto (2008) pointed out that LCA needs to be complemented with other assessments, such as land use and resource mapping. Other assessment tools comprise agro-economic market models and scenario building at the macro level[15]. The very recent estimates of indirect-land use changes due to biofuels diffusion are an important step in this direction[16]. This will be further described in Section 5.

Altogether, life-cycle assessments have shown a wide variation between different types of biofuels and their production technologies with regard to their potential to reduce fossil energy requirements and GHG emissions. Other impacts, such as eutrophication, where biofuels cause higher environmental loads than fossil fuels, have been less well addressed by LCA studies. The high variation of results depends not only on the differences between technologies, but also to a considerable extent on assumptions and constraints in the application of the LCA methodology, and in particular, insufficient data on N_2O emissions. Improvement of the product chain oriented life-cycle approach seems necessary, and is ongoing, but basic deficiencies may only be overcome through the use of complementary analytical approaches which capture the overall impacts of biofuels in the spatial context.

LCA needs to be complemented with other assessment tools considering various impacts of increased use at the macro level.

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[15] See for instance Hertel et al. 2009; Lee et al. 2005; Verburg et al. 2008

[16] See for instance the carbon-intensity values proposed by the California Low Carbon Fuel Standard for land use change attributed to certain biofuels: California Air Resources Board (2009) Proposed Regulation to Implement the Low Carbon Fuel Standard: Initital Statement of Reasons. Volume 1. March 5, 2009. http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

Section 5: Impacts through increased demand and land use change

Land is a limiting factor for biomass production. Moreover, land use change for expanded agriculture may lead to increased GHG emissions and a loss of biodiversity.

5.1. Actual and planned land use for fuel crop production

In 2007, fuel crops for transport biofuels covered about 26.6 Mha (Ravindranath et al. 2009), or 1.7% of global cropland as compared to 13.8 Mha, or about 0.9% of global cropland in 2004 estimated by OECD/FAO (2007). Increase of production in 2008 (see 3.1.2) led to about 35.7 Mha or 2.3% of total cropland being used for fuel crops[17]. The cropland for biofuels was mainly distributed among the US and Canada (17.5 Mha), the European Union (8.3 Mha) and Latin America (6.4 Mha). Due to more favourable climatic conditions, cropland for biofuel production is expanding, in particular, in tropical countries.

This development is driven by volume targets rather than by land use planning.

The EU has recently reconsidered the requirements for set-aside land in order to allow farmers to respond to higher demands for agricultural production. A part of the official set-aside land is already used for non-food production, including energy crops. It is expected that 1.6 to 2.9 Mha will be returned to agricultural food production, representing only 0.9 to 1.6% of the agricultural land in the EU-27 (EC, 2007b). No major changes between land use categories may be expected within the EU due to increased use of biofuels. Though European biofuel mandates – as shown in Table 3.3 - will require imports from developing countries. In other words, the European impact on agricultural land is being displaced to developing countries.

In the USA, the potential for biofuels production has been estimated at 60 billion litres of ethanol from corn, implying agricultural land expansion of 12.8 Mha (Searchinger et al. 2008). Genetically modified varieties for biofuel crops are used to a large extent. Besides concerns on conservation land, the actual use of additional cropland is mainly determined by economic considerations. The same applies to Russia, where the government expects significant potentials for additional cropland for biofuels (Bustamante et al. 2009).

Only in tropical regions with sufficient rainfall can fuel crops such as sugar cane (like in Brazil) and oil palms (like in Indonesia and Malaysia) be cultivated with maximum productivity per hectare. Policies in those countries support the expansion of production in order to enhance revenues from biofuels.

In Brazil, biofuels are mainly produced as bioethanol from sugar cane, and biodiesel from soy. In terms of land use, the latter has had a greater impact. Soy bean production occupies more than 6 Mha in the plateau regions of Central Brazil, primarily produced for food and feed; genetically-modified varieties are widely grown. Today, soy bean oil is increasingly used for biodiesel production. The by-product oilcake is used as fodder and has been exported by Brazil to a large extent, for instance, to the EU. The expansion of soy production into the Amazon has raised severe environmental concerns, and led to the agreement of soy producers on a so-called "soy moratorium" according to which further expansion of soy should not use primary forests (ABIOVE et al. 2008).

Land is a limiting factor for biomass production.

Land use change for expanded agriculture may lead to increased GHG emissions and a loss of biodiversity.

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[17] Considering regionally-specific data, Johnston et al. (2009) recently showed that many earlier studies applying commonly used yield data (e.g. those reported by Worldwatch Institute 2006) probably have overestimated actual biofuel yields and thus underestimated current area requirements. Therefore, some of the land requirement data in Section 5 may represent rather conservative estimates.

In Brazil, the total cropping area for soy beans could potentially be increased from 23 Mha in 2005 to about 100 Mha (Kaltner et al. 2005). Such growth would meet the total demand of diesel in Brazil in 2020, assuming that soy bean yields could be increased over the same period by 25%. In addition, Brazil plans to increase the area for palm oil production. Oil plants like castor could contribute to regional sustainability, and this development is also selectively supported by the Brazilian government with the "Social Seal" programme.

The total arable land of Brazil currently covers about 60 Mha. Considering government regulations for set-aside land, Matthey et al. (2004) estimated that an additional 60 Mha of land could potentially come into agricultural production[18]. Also the National Committee, ICID, claimed a potential to cultivate another 60 Mha in Brazil which could be used for rainfed agriculture[19].

From 1960 to 2007, the area planted with sugar cane in Brazil increased from ~1.4 million to 7 Mha (Martinelli and Filoso 2008). Some 65% of new planting of sugar cane in Southeast Brazil has been on land that was previously pasture; the rest was previously used for other crops (CONAB 2008). In 2008, the planted area increased to 9 Mha. The productivity of sugar cane also increased dramatically from 45 (1960) to 81 Mg/ha (2008), including through the use of genetically-modified strains. Ethanol production consumes 57% of the sugarcane yield (CONAB 2008).

Activities to align expansion of cropland with nature conservation and environmental protection are ongoing in Brazil, as reported by Bustamante et al. (2009). For instance, the Brazilian Agricultural Research Corporation, EMBRAPA, has developed agro-ecological zoning for sugar cane using climate, soil data, conservation units and topography. This agro-ecological zoning should avoid the expansion of sugar cane plantations, in particular in the Amazon and Pantanal, and concentrate expansion in the savannahs of Central Brazil (Cerrado).

The Brazilian Federal Government, through the Ministry for the Environment, is currently preparing an agro-economic zoning which will determine the areas where agriculture expansion can take place. Flaskerud (2003) estimated that the overall expansion of Brazilian cropland will include 42% in the Cerrado area, 7% in the Amazon rainforest and 51% on former pastureland. Also soy bean planting may be expected to expand primarily on grasslands and savannah land.

Palm oil has been mainly used for cooking, to produce margarine and food additives, and for cosmetics, and the oilcake has been used as animal feed in European intensive animal production. More than 90% of the palm oil was for the European market. Malaysia and Indonesia now foresee increased production of palm oil and biodiesel, mainly for exporting to growing biofuel markets in Europe, the US and China. So far, the share of palm oil of global biodiesel production has only been about 1%. Recently, however, 95% of the increased production of palm oil in Malaysia and Indonesia was driven by the growing demand for biodiesel. New biodiesel plants are built partly with support from foreign enterprises.

In Southeast Asia, palm oil expansion is one of the leading causes of rainforest destruction (Hooijer et al. 2006; UNEP 2007; Pastowski et al. 2007). Palm oil producers often prefer to expand into forestland rather than planting on abandoned agricultural land, since recently cleared forests need less fertiliser and profits are higher (Clay 2004[20]).

In Indonesia, natural rainforests and peatlands have been converted to agricultural cultivation for decades. It reached a remarkable extent in the course of the Mega Rice Project, on 1 Mha of natural forest and peatland area in Central Kalimantan in the mid 1990s. As a consequence of increasing land use and land cover changes, huge forest fires in 1997/1998 destroyed 10 Mha of rainforest area in Borneo, Sumatra and New-Guinea, boosting global atmospheric CO_2 concentrations in 1997 to almost twice the average values of years before and after 1997 (Schimel and Baker 2002; Page et al. 2002). In recent years, rainforest and peatland is increasingly being cleared for planting oil palms (Hooijer et al. 2006; UNEP 2007). Expanding cultivation area for oil palm by a further 20 Mha, compared with the current 6 Mha, is planned by the Indonesian government (Colchester et al. 2003).

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[18] Note that this relates to all possible crops, not only for biofuels

[19] http://www.icid.org:80/cp_brazil.html

[20] Worldwatch Institute (2006) chapt. 12 note 31

Two-thirds of the current expansion of palm oil cultivation in Indonesia is based on the conversion of rainforests, with one third planted on previously cultivated or fallow land (Grieg-Gran et al. 2007). In the rainforest areas, one quarter of the land is on peat soil with high carbon content - resulting in particularly high greenhouse gas emissions when drained. By 2030, a share of 50% from peat soils is expected (Hooijer et al. 2006).

If current trends continue, the total rainforest area of Indonesia would be reduced by 29% as compared to 2005, and would only cover about 49% of the original area from 1990 (Bringezu et al. 2008).

Altogether, the ambitious targets of both industrial and developing countries for biofuel use are reflected by policies and trends to expand cropland, particularly in the tropics. Depending on the region, actual land use change leads to direct conversion of pastures or other grasslands as well as of savannahs and forests.

5.2. Land requirements for projected biofuel use

Land requirement estimates for future biofuels vary significantly based on the assumptions made on the type of feedstock, geographical location and yield increases. Conservative trajectories, which project a moderate increase in biofuel production and use, have been developed under the assumption that no additional policies would be introduced to further stimulate demand. These range between 35 Mha to 166 Mha in 2020 (Table 5.1). On the other hand, the highest estimates of potentials of biofuel production foresee land requirements up to 1668 Mha in 2050 (Table 5.2). For comparison: total global cropland[21] comprised 1562 Mha, and permanent pastures, which comprise most of the natural grasslands and savannahs, extended 3406 Mha in 2005 (FAOSTAT online).

Eickhout et al. used the rather favourable case of biodiesel from palm oil for their EU estimate. Taking instead biodiesel from soya, which has much lower yields, would result in significantly higher global land requirements. Our calculations based on the actual proportion of soy and palm oil biofuels assumed by the EC (2006) indicate that the land requirements of the EU might increase global land requirements for biofuels to 80 Mha in 2020[22] (Table 5.1).

Based on six different scenarios, Ravindranath et al. (2009) estimated the cropland requirements for a 10% supply of global fuel demand in 2030 (Table 5.2). The authors assumed constant crop yields, considering the uncertainty of further increases and that the improvement of crop varieties and increased inputs might be balanced by the expansion of crops onto "marginal" lands, which will cause yields to decrease. Under each scenario, either jatropha, palm oil or soy bean would completely meet the projected demand for biodiesel, and maize or sugar cane would completely meet the projected demand for ethanol. The authors stressed that soy bean, maize and palm oil are also food crops, particularly in many developing country regions and thus, may have added constraint and a limited potential for meeting the biofuel demands. According to the estimates, the least amount of land would be required when palm oil and sugar cane were considered (118 Mha), whereas soy bean and maize crops would require 508 Mha.

Ambitious targets of both industrial and developing countries for biofuel use are reflected by policies and trends to expand cropland.

Land requirement estimates for future biofuels vary significantly based on the assumptions made on the type of feedstock, geographical location and yield increases.

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[21] including permanent cultures

[22] The European Commission in its impact assessment of the Biofuels Directive had assumed significant shares of imported biodiesel from soya (EC 2006). On the other hand the EU also assumed significant contributions from second generation BtL and cellulosic ethanol, lowering the total land demand for biofuels. The overall result would be a global land requirement of the EU in 2020 of 14.8 Mha at 7% biofuels share (with ca. 49% on foreign land), 23.1 Mha at 14% biofuels and more imports (with ca. 49% on foreign land), and 27.6 Mha at 14% and more domestic supply (with ca. 34% on foreign land).

Table 5.1: **Projections of future global biofuels use and cropland requirements**

I. Projections

Source	Target	Energy contribution	Cropland requirement
IEA (2006) reference case	3% of transport energy in 2030	92 Mtoe (3.9 EJ)	34.5 Mha
OECD/FAO 2007	Projected increase until 2020	n.a. (default crop reference development)	35 Mha
Eickhout et al. 2008	Like OECD/FAO 2007 plus EU 10% and USA target for 2020	n.a.	60 Mha
Eickhout et al. modified by own calculation and after CEC (2006)	Like OECD/FAO 2007 plus EU 10% and USA target for 2020	n.a.	64 to 80 Mha*
RFA (2008)	All major countries and regions were to attain their stated targets to 2020	n.a.	56 to 166 Mha**

Table 5.2: **Potentials of future global biofuels use and cropland requirements**

II. Potentials

Source	Target	Energy contribution	Cropland requirement
IEA (2006), alternative scenarios	Alternative policy scenario: 5% of transport energy in 2030	147 Mtoe (6.2 EJ)	52.8 Mha
	Second generation biofuels case: 10% of transport energy in 2030	294 Mtoe (12.3 EJ)	58.5 Mha
Dornburg et al. (2008)	Bionergy potentials from agricultural and pasture lands in total in 2050	ca. 2860 Mtoe (120 EJ)	180 Mha of abandoned agricultural land, and a further 300 Mha of extensively used grasslands
Gurgel et al. (2007): a) reference scenario; b) policy scenario	Bionergy potentials in total 2010 to 2100; data here for 2050	a) 836 to 931 Mtoe *** (35 to 39 EJ)	a) 419 to 476 Mha***
		b) 2914 to 3201 Mtoe *** (122 to 134 EJ)	B) 1461 to 1668 Mha***
Ravindranath et al. (2009)	10% by energy of gasoline and diesel demand in 2030	339 Mtoe (14.2 EJ)	118 to 508 Mha***
IEA (2008) BLUE Map scenario	26% by energy of total transport fuel demand in 2050	611 Mtoe (25.6 EJ)	160 Mha

* lower value from linear interpolation of estimates for 7% biofuels to 14% biofuels (the latter as average of more domestic supply and more imports), upper value for 14% and more domestic supply.

** The lower figure takes into account the avoided land use benefits of co-products, 2nd generation technologies from wastes and residues and assumes significant improvements in yield. The higher estimate is a gross figure, for the low yield scenario, not taking into account the anticipated benefits of co-products and without a positive contribution from 2nd generation technologies.

*** The lower figures refer to the OLSR version, higher figures for the PCCR version of the EPPA model (MIT Emissions Predictions and Policy Analysis Model). OLSR stands for Observed Land Supply Response and considers the response in land conversion in recent years representative of the long-term response. PCCR means Pure Conversion Cost Response and simulates unrestricted conversion of natural forest and grassland as long as costs are covered by returns.

**** The least amount of land is required when palm oil and sugarcane is considered (142 Mha), whereas soybean and maize crops at indicative yields require 600 Mha.

n.a. = not available

Source: own compilation after sources indicated in table.

According to the estimates of Ravindranath et al. (2009), the total land area required for producing biofuels to meet the 10% petroleum fuel substitution scenario would be equal to 3-15% of the permanent pastures. Permanent pastures may have previously avoided conversion to cropland because of their unsuitability for cropping due to infertile soils or the lack of precipitation. Consequently, the extent of area required may not reflect the likely land categories that will actually be used for producing biofuels. If, in contrast, crop-land is used for biofuel production, the land area required could account for 8 to 36% of the current arable area. Furthermore, the authors regarded it quite likely that oil palm could replace wetlands and forests. Current rates of global deforestation are about 13 Mha per year (FAO 2006). If present trends continue, 286 Mha would be deforested by 2030. The biofuel land demand scenarios considered by Ravindranath et al. represent a land demand equivalent to 40 to 180% of ongoing deforestation. Thus, biofuels, depending on where the biomass is produced, could have globally significant impacts through land use change.

5.3. Impacts of growing demand

The expansion of cropland for biofuels may lead to large scale land conversion. Clearing the natural vegetation mobilises the carbon storage in vegetation and soil, and may lead to a carbon debt which may render the overall GHG mitigation effect of biofuels questionable for coming decades. In addition, biodiversity would be severely affected.

5.3.1. Land use change induced GHG emissions

Recent studies have shown that the land conversion from forest, savannah, grassland and abandoned land to biofuel crops leads to significant CO_2 emissions and 'carbon debts' ranging from few to several hundred years (Fargione et al. 2008; Australian Biofuel Institute 2008; Gibbs et al. 2008; Searchinger et al. 2008; Fritsche 2008). The carbon debt is the time necessary to counterbalance the CO_2 emissions resulting from the conversion of a native ecosystem by mobilising the carbon stocked in the vegetation and organic matter above and below ground[23]. The conversion from forest peatland to palm oil releases 3452 tCO_2/ha and requires 423 years to pay the 'carbon debt' (Fargione et al. 2008).

Searchinger et al. (2008) noted that when more agricultural land is used for growing crops for biofuels, feedbacks through the global economy tend to result in land conversions – including tropical deforestation somewhere. These land conversions can have very negative consequences on greenhouse gas emissions, and should be included in the net greenhouse gas balance of the biofuels. Despite some methodological weaknesses in the original approach, the fact that displacement effects can happen seems rather undisputed (see also Searchinger 2009).

Stickler et al. (2007) estimate the average forest carbon for tropical forest suitable for palm oil plantations at 182 tonnes C/ha. Palm plantations contain about 36 tonnes C/ha averaged over their 25-30 year lifespan (Henson 2003). Thus, Ravindranath et al. (2009) estimated emissions of 535 tonnes of CO_2/ha from conversion of tropical forest to palm plantations. They ignored potential emissions from soil carbon and did not factor in reduced emissions from forest products as much tropical rainforest is cleared by burning.

Land conversion from forest, savannah, grassland and abandoned land to biofuel crops leads to significant CO_2 emissions and 'carbon debts'.

Ravindranath et al. (2009) estimated the CO_2 emissions from six global scenarios of land conversion, assuming that the emissions will take place over a 30 year period. The total CO_2 emission from 10% of the global diesel and gasoline consumption during 2030 is estimated to be 0.84 Gt CO_2, of which biofuels could substitute 0.17 to 0.76 Gt CO_2 (20-90%), whereas the annual CO_2 emission from land conversion alone is estimated to be in the range of 0.75 to 1.83 Gt CO_2 (Ravindranath et al. 2009). Thus, the potential emissions from direct land conversion to biofuel crops by growing first-generation biofuel crops is significant.

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23 Determining the carbon debt critically depends on the assumptions made and parameters considered. For instance, focussing on North America and carbon emissions, Kim et al. (2009) modelled that no-tillage cultivation may increase soil carbon and thus reduce the carbon debt of biofuels.
In contrast, field measurements in pampas in Argentina indicated that no-tillage would lead to increased N_2O emissions which would overcome the mitigation potential of increased soil carbon in about 35 years (Steinbach and Alvarez 2006).

Hooijer et al. (2006) concluded that deforested and drained peatlands in SE Asia are a globally significant source of CO_2 emissions and a major obstacle to meeting the aim of stabilising greenhouse gas emissions, as expressed by the international community. Hooijer et al. (2006) therefore recommend that international action be taken to help SE Asian countries, especially Indonesia, to better conserve their peat resources through forest conservation and through water management improvements aiming to restore high water tables.

Policymakers are aiming to overcome the negative environmental and social consequences of biofuels by introducing sustainability standards. An important point is the reduction of GHG emissions through the use of biofuels, which should be at least 35% and from 2017 onward 50% for existing and 60% for new plants according to the sustainability criteria required by the European Union (EU 2009b). The US Energy Independence and Security Act of 2007 requires that 21 of its 36 billion gallons of mandated biofuels achieve roughly 50% reductions in greenhouse gases after accounting for emissions from indirect land use change. The California Air Resources Board is developing regulations for a "low carbon fuel standard" that would similarly assign greenhouse gas levels to different biofuels that incorporate land use change, and require that the total mix of fuels sold in California reduce greenhouse gas emissions overall.

As long as the global cropland required for agricultural based consumption grows, displacement effects, land conversion and related impacts may not be avoided through selected production standards of biofuels.

However, a basic methodological challenge lies with the fact that pure product and production specific standards are hardly capable of controlling indirect effects of land use change. Whereas it is possible to define default values of GHG emissions and account for the conversion of different biomes, there by excluding hectares that have been transformed from non-agricultural land in recent years, these product standards cannot avoid displacement effects. If the overall demand for biomass grows faster than the average yields, it can only be supplied by a net expansion of cultivated area. It is therefore of paramount importance to sufficiently estimate the dynamics of biofuel cultivation, especially their global land requirements and subsequent impacts, in order to assess the net effect of increasing the quotas, and use, of biomass and biofuels in certain countries.

The land demand for providing 10% of transport in the EU with biofuels would require additional land abroad of ca. 5 Mha for palm oil and 1.5 Mha for sugar cane, increasing the total EU land requirement to ca. 25 to 30 Mha (Eickhout et al. 2008). Even the introduction of new techniques like second-generation biofuels would not lower the land demand of the EU to less than 20 Mha.

Bringezu et al. (2009) showed that an increase in the use of biomass, and in particular biofuels, in Germany would lead to an expansion of cropland requirements. Under business-as-usual conditions, with ongoing trends heading towards a biofuel share of 20 to 25% in 2030, the global land use for all agricultural goods consumed in Germany would expand by 2.5 to 3.4 Mha by 2030. The expansion would occur mainly in tropical regions due to the land production of biodiesel (in particular from soy and oil palm). The expansion of the net consumption land for agricultural goods would lead to 13 to 27 million tonnes of GHG emissions through land conversion. Without the consideration of yield increases for food production, which will reduce overall land requirements, the specific effect of biodiesel consumption would be even worse. In 2030, the estimated consumption of biodiesel would lead to emissions of 37 to 54 million tonnes CO_2 equivalent from land conversion. Taking GHG mitigation of biodiesel through substitution of fossil diesel into account, a net effect of 23 to 37 million tonnes of additional greenhouse gases would result from the use of expanded production areas abroad. In case these trends continue, a net relief for the climate through Germany's imported diesel quantities could not be expected before the period 2040 to 2050.

Altogether, the land conversion for biofuel cropland could lead to significant GHG emissions. Even if abandoned land and pastures were mainly used, a global average of up to 10% biofuel use for transport would render the overall mitigation effect of the use of first-generation biofuels questionable. As long as the global cropland required for agricultural based consumption grows, displacement effects, land conversion and related impacts may not be avoided through selected production standards of biofuels.

5.3.2. Land use change impacts on biodiversity

Land use change in terms of converting natural habitats to human dominated land use has been historically identified as the largest threat to global biodiversity. Besides biodiversity, ecosystem services are also hampered, with biodiversity and ecosystem functioning being closely related (Millenium Ecosystem Assessment 2005; EEA 2008d).

One global hot spot of biodiversity is the Brazilian Cerrado, which represents about 9% of the tropical savannahs world-wide (Myers et al. 2000). It has been earmarked for the expansion of the Brazilian cropping area, in particular for fuel crops (see 5.1). The overlap of potential areas for sugar cane expansion with priority conservation areas of extreme biological importance is 70% in the Cerrado region, 16% in the Amazon region and 40% in the Pantanal (Fig. 5.1). Most of these priority areas for conservation are not under protection nor have special programs for sustainable development. In a recent revision made by the Brazilian Ministry of Environment, areas of high biological relevance for conservation represent 19.7% of the Cerrado and Pantanal. Recent studies in the Cerrado region showed the expansion of sugar cane over some of these unprotected priority conservation areas in spite of the large area already converted in this biome that could be used for this expansion (Bustamante et al. 2009).

Land use change in terms of converting natural habitats to human dominated land use has been the largest threat to global biodiversity.

Figure 5.1: **Map of the priority conservation areas of high relevance (dark blue) and potential area for sugar cane plantation (light blue) in Brazil**

Source: Machado et al. 2006

Sala et al. (2009) found that increased biofuel production may have large impacts on biological diversity, using species richness and estimated as the number of species of plants and animals per unit area as an indicator. Increased biofuel production would result in habitat loss, increased invasive species and nutrient pollution. Species and genotypes of grasses suggested as future feedstocks of biofuels may become critical as invaders. Intensive fuel cropping leading to nutrient emissions to water and air will affect species composition in aquatic and terrestrial systems. Increased biofuel production may also have some positive impacts on biodiversity by ameliorating the rate of change of atmospheric composition and global climate change when net benefits for GHG emissions, after considering displacement effects (which is uncertain according to the results presented in 5.3.1), are achieved. Conservation agriculture for the shelter of anthropogenic biomes plays only a minor role with regard to area and production potential.

The effect of expanded biofuel production on biodiversity will vary depending on the region and the type of biofuel production. Areas of the world that have already experienced large losses of biodiversity would be most vulnerable in comparison to areas that have not yet lost significant biodiversity. Similarly, communities with many species may lose more species than species-poor communities experiencing similar disturbances. As biofuel production intensifies, more biodiversity will be lost.

Negative and positive effects of biofuels on biodiversity operate differently across spatial and temporal scales.

Negative and positive effects of biofuels on biodiversity operate differently across spatial and temporal scales (Sala et al. 2009; Lysen and van Egmond 2008). Negative effects occur at all scales, from local to regional and global. Conversion of protected land into biofuel production may result in local extinctions, loss of aquatic species in distant habitats (regional effect) and in global extinctions if local endemic species are lost. Many of these negative effects of biofuel production on native biodiversity will be realised instantaneously or after a short period of time (years to decades). Any positive effects would occur primarily at the global and long-term scale by ameliorating climate change, though these positive effects should scale down to local scales by reducing the extent of local impacts of climate change. Consequently, simple qualitative analysis is not adequate to assess the final outcome of expanded biofuel production on biodiversity. Instead, quantitative models of biofuel production need to take into account local, site-specific threats to biodiversity, regional impacts, and potential longer-term benefits for biodiversity that may be realised in the distant future.

Eickhout et al. (2008) investigated the effects of climate change versus land use change on biodiversity, making the broad assumption that climate change mitigation will avoid biodiversity loss whereas further land use conversion will increase biodiversity loss. With quantitative modelling, they sought to assess how biofuel crops can contribute to a positive synergy between the EU climate and biodiversity targets.

Their results clearly indicate that the intensive production of biofuels has direct negative impacts on biodiversity, unless already intensively managed arable land is used. Any positive impact of biofuel production through avoided climate impacts will affect biodiversity only after many crop rotations. Only a longer term use of biofuels would lead to positive outcomes for biodiversity, although this term will be around 100 years[24].

The biodiversity balance mostly depends on the actual land that is converted into biofuels and on the number of years that a particular biofuel crop is grown. Figure 5.2 shows the results of Eickhout et al. (2008) for wheat and palm oil. The first year of production (2008) is dominated by the negative effect of land use in most cases. This creates a 'biodiversity debt' (cf. carbon debt in Fargione et al. 2008). In the following years, the positive effect of avoided climate change becomes 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. In contrast, biofuel production on recently abandoned lands that were under intensive agricultural management, would immediately result in positive effects, as the former land use does not present valuable biodiversity.

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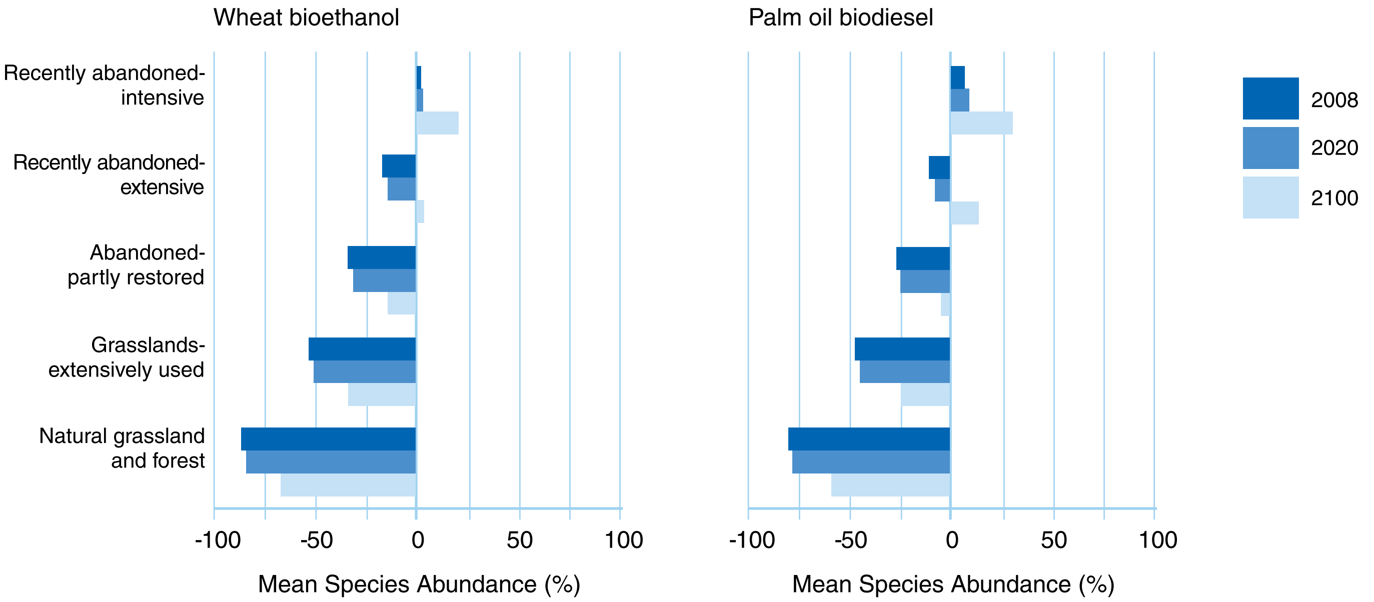
[24] Note that there is a higher uncertainty concerning long-term benefits of climate change mitigation, than concerning negative/positive immediate effects of changed land-use.

Figure 5.2: Biodiversity balance of land use change: land cover conversion vs. avoided climate change for wheat production and palm oil production



Source: Eickhout et al. 2008

When land recently abandoned from extensive cropping is converted to fuel crops the negative impact on biodiversity prevails for several decades. If abandoned arable land had time to restore at least part of the natural vegetation, conversion to fuel crops will not lead to a positive effect within a hundred years. The losses in species abundance are even higher when extensively used grasslands are converted.

In essence, Eickhout et al. (2008), applying the biodiversity balance for different crops on different land types, have shown that greenhouse gas reductions from biofuel production will not compensate for the biodiversity losses from increased land use conversion, even within a time frame of several decades. Beneficial effects for biodiversity are only expected when abandoned, formerly intensively used agricultural lands or (moderately) degraded lands are used. On these lands, biofuel production can even lead to gains in biodiversity.

Beneficial effects for biodiversity are only expected when abandoned, formerly intensively used agricultural lands or (moderately) degraded lands are used.

Section 6: Options for more efficient and sustainable production and use of biomass

Biomass has been and will be part of the overall energy mix. However, transport biofuels will probably only make a small contribution to future energy supply. While their production efficiency could be improved by increasing the productivity of existing cropland and expanded by planting on degraded land, biomass may be more effectively used for stationary energy supply and material applications, or both. The use of residues and waste could widen the available feedstocks with the least environmental burden. Nevertheless, land use may still be a relevant constraint for non-food use of biomass. Hence, in the overall energy mix, alternative renewable energy systems, which are less harmful for the environment, should be considered for their local suitability in striving to optimise resource efficiency.

6.1. Increasing yields and optimising agricultural production

The future potential of biofuels to contribute to energy supply is largely contingent on the ability to increase yields on existing farmlands. Yields may be increased by adjusting crops and cultivation methods.

Regions differ with regard to their potential to increase agricultural productivity and to optimise production. Yields are currently below their potential in many developing countries, whereas developed countries have surpassed natural yield potentials due to irrigation, multiple cropping, input use and production practices (Fig. 6.1) (FAO 2008). Large potentials for increased yields of food and non-food biomass seem to exist for instance in sub-Saharan Africa, where development is hampered by insufficient investments in infrastructure, production capacities, education and training. In developed and developing countries with high agricultural production levels, limiting pollution of watercourses caused by fertiliser may constrain future yield growth. For instance, crop productivity in high income countries (HIC) is higher than in low income countries (LIC) and middle income countries (MIC), implying potential for the latter to improve[25]. Indeed, the rate of yield growth between 1992 and 2002 was marginally higher in both MIC and LIC than in HIC, with the exception of sub-Saharan Africa, where yield levels have remained almost unchanged (Fig. 6.2).

Land productivity in LIC is only about half that of HIC on average and 64% that of MIC. In these regions, high potential rain fed agriculture areas do not perform much better than low potential rain fed agricultural areas[26]. This is a considerable difference to HIC, where agricultural production has been optimised to make use of natural conditions (Hazel & Wood 2008). Lal (2006) compared countries and regions with similar total and seasonal rainfall, irrigated versus rain-fed production systems and tillage and cropping methods and estimated that the average yield of wheat in India could be increased from 2.6 t/ha to 4.0 t/ha and corn could be increased from 1.7 t/ha to 3.5 t/ha.

Yields are currently below their potential in many developing countries, whereas developed countries have surpassed natural yield potentials.

Recent efforts in some developing countries demonstrate the harnessing of this potential. For example, the use of fertilisers, improved seeds and extensive agricultural extension efforts have resulted in doubling or tripling cereal crop yields at local levels in 10 African countries (Bekunda et al. 2009[27]). Over the past three years, Malawi has doubled national maize yields (Bekunda et al. 2009[28]). Batidzirai et al. (2006) estimate that productivity in Mozambique could be increased seven times with just moderate use of agricultural technologies, such as fertilisers, pesticides, selected seeds, and large-scale harvesting practices. In Brazil, improved management could

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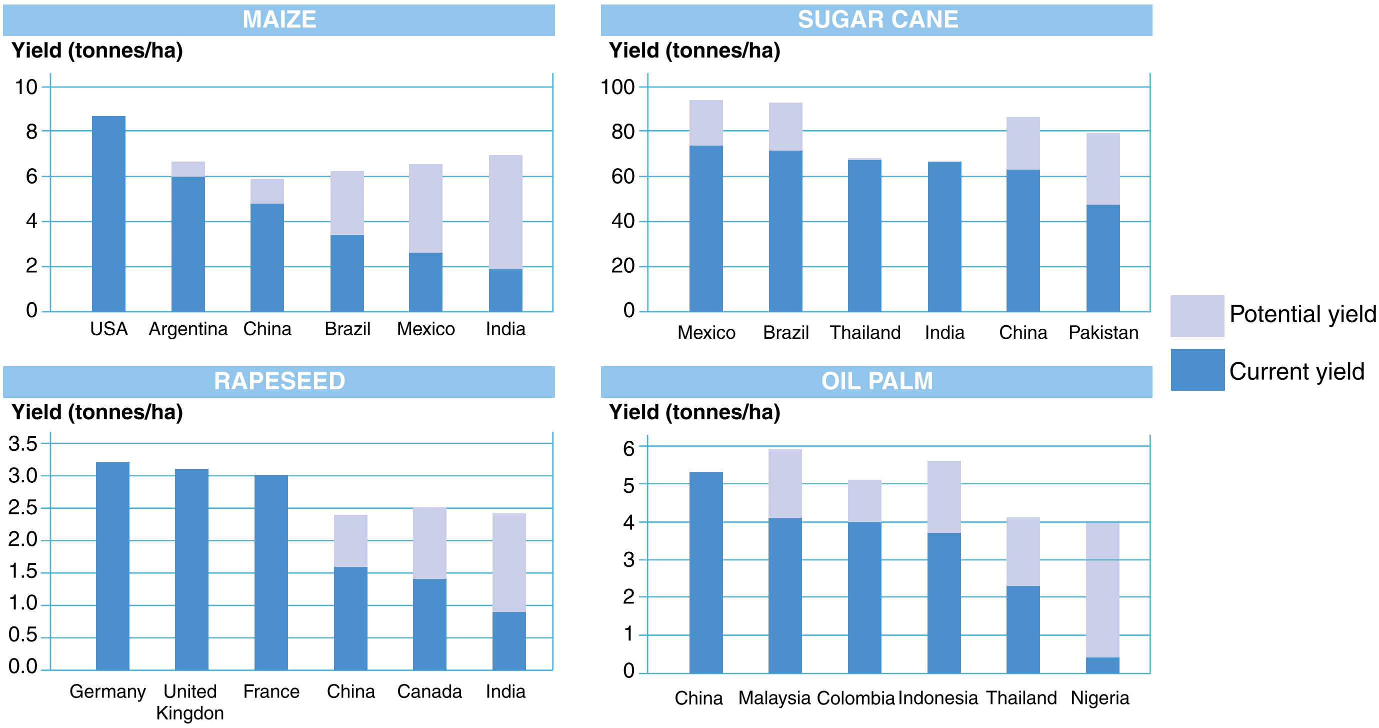
[25] LICs refers to countries whose GNI/capita was less than US$ 825, middle income between US$ 826 - 10,065, and high income more than US$ 10,065 as defined by the World Bank, 2005 and reported by Hazel and Wood (2008).

[26] High potential rainfed agricultural areas have a growing period length of at least 180 d yr^{-1} and a slope less than 15%. Low potential rainfed agricultural areas have a growing period length less than 180 d yr^{-1} and an average slope of 15% or greater (Hazel & Wood 2008).

[27] Based on Sanchez et al. 2007

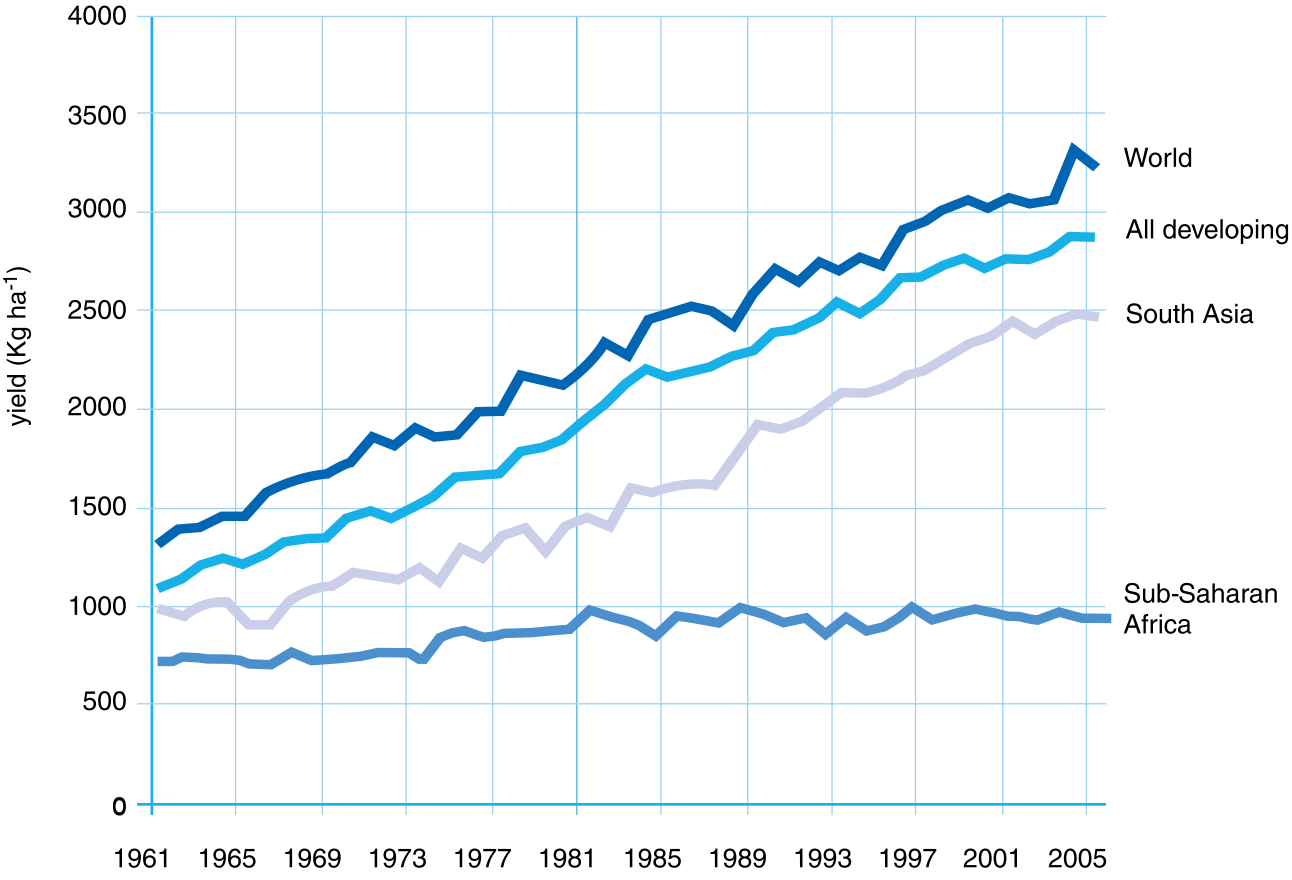
[28] Based on Denning et al. 2009

Figure 6.1: Potential yield increase for selected biofuel feedstock crops



Source: FAO 2008

Figure 6.2: Global trends in cereal yield by region (1961-2005)



Source: Hazel & Wood 2008 (adapted from FAOSTAT 2006) result in yield increases in the range of 20 percent over the next ten years, not including GMOs. FAO (2008) suggests that demand for biofuels may trigger changes in yields, both directly in the production of biofuel feedstocks and indirectly in the production of other crops – provided that appropriate investments are made.

Improved institutional setting can contribute to increased agricultural production, and vice-versa. One successful example is the Kilombero Sugar Company (KSC) in Tanzania, which combines large-scale sugar cane production with small-scale farming. Their outgrower scheme has enhanced local income, and returns have been invested in medical and educational infrastructure (Bekunda et al. 2009).

In countries with high crop yield levels, yield increases seem to have slowed down. There are natural limitations with regard to soil, sunlight and water. An important constraint is the increasing level of nutrient pollution. Agriculture in many western countries is the biggest single source of nutrient loading to watercourses. The increase in corn to support ethanol goals in the United States is predicted to increase nitrogen inputs to the Mississippi River by 37%[29]. Crops requiring less fertiliser and still providing an adequate feedstock for ethanol production would be an alternative (Connor et al. 2009). Biofuels that do not require high energy inputs and that can be grown in polycultures of native species would also be more biodiversity friendly than monocultures (Tilman et al. 2006).

Besides better plant selection, other possibilities to improve productivity include plant breeding, cultivation techniques, harvesting, storage, transport and processing (OECD/IEA 2008). Genetic manipulation is also being used, for instance, to increase the lignocellulose content for 2nd generation feedstocks and to provide micro-organisms delivering more efficient enzymes for industrial processing (see for example Bon & Ferrara 2007; Larson 2008; Sticklen 2008; Zarrilli 2008), though the risks for ecosystems seem difficult to assess, and some advocate the application of the precautionary principle to these technologies (see CBD & UNEP 2003; Herrera 2007).

Although significantly higher agricultural yields can be expected for fuel crops (as for other crops) in certain regions, investments and time are needed to mobilise these potentials, suggesting that the overall global trend will probably be a rather moderate increase of yields. This may imply that the expected growing demand for food and non-food biomass can only be fulfilled when global cropland is expanded (as explained in section 3). At the regional level, the substantial new investments being made in biofuel production in many African countries may provide the infrastructure needed to boost overall agricultural production in a continent that has seen much less investments so far compared to others (as argued for instance by Bekunda et al. 2009), although this remains to be proven and the risk of exacerbating competition between food and fuel (see for example SWISSAID 2009) remains a concern.

Large potentials for increased yields of food and non-food biomass seem to exist for instance in sub-Saharan Africa, where development is hampered by insufficient investments in infrastructure, production capacities, education and training.

6.2. Restoring degraded land

To avoid tradeoffs between expanding biofuel cultivation and conservation of biodiversity, three types of land have been suggested for potential agriculture expansion: "marginal" land, degraded land and abandoned land. "Marginal" land comprises all non-cultivated area (not used as cropland) where actual primary production is too low to allow competitive agriculture. Degraded land has been cultivated before and become marginal due to soil degradation or other impacts resulting from inappropriate management or external factors (e.g. climate change). Abandoned land[30] comprises degraded land with low productivity plus land with high productivity (e.g. where forest is regrowing)[31].

Some biofuel crops can grow on degraded land and help restore its productivity.

Some biofuel crops can grow on degraded land and help restore its productivity. One example is switchgrass, which may even improve soil quality and productivity (Simpson et al. 2009). It can have eight times higher below ground biomass and as much as 55% more total soil organic carbon than corn/soy bean over two rotations (Tufekcioglu et al. 2003). The use of leguminous nitrogen-fixing plants is an option to improve soil fertility (UN-Energy 2007). Jatropha may also improve soil quality and can

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[29] In the Mississippi basin the high fertiliser input for corn and resulting drainage is in conflict with water quality targets for the Gulf of Mexico (see 4.2)

[30] Note: set-aside land does not belong to this category of abandoned land.

[31] Further definitions were discussed at the UNEP/IUCN/RSB/Oeko Institute workshop held in Paris in 2008, http://www.unep.fr/energy/activities/mapping/.

grow under less optimal conditions, perhaps enabling the planting of other crops over time. However, it has yet to be empirically proven at which scale jatropha production may provide a net benefit as high jatropha yields (necessary for competitive transport fuel production) require favorable growing conditions for plantations, including sufficient nutrient and water availability (FAO 2008; de Fraiture and Berndes 2009), whereas small scale use of jatropha, e.g. for electricity generation, is often applied in the form of hedges and intercropping, so that the plant oil is rather a by-product for local use (MFC 2008). Halophytic crops thrive in relatively high saline areas, such as some deserts and in coastal areas, where major crop species are unable to grow. During their growth, salt is taken up. Such crops could clean soils of high salinity (Hendricks & Bushnell 2008), although saline agriculture[32] is still in its infancy (Rozema & Flowers 2008) and research on ecologically sound cultivation of marsh crops is ongoing (see for example Ruan et al. 2008). Finally, soil contaminated with heavy metals (comprising about 10,000 ha in the USA and Europe) could be restored by growing energy crops that take up these pollutants (Ignaciuk 2006). For example, Lewandowski et al. (2006) performed a case study in Germany regarding the potential of willow to clean contaminated soils, and later be burned as a fuel, finding that there was an economic benefit for farmers under certain conditions.

The use of degraded lands is generally less profitable than the use of productive land.

Small-scale biofuel production on degraded land has had a positive impact on energy provision in several developing countries.

Lower yields mean that the use of degraded lands is generally less profitable than the use of productive land. If mechanised cultivation is required for restoration, the required investment can act as a disincentive. Nevertheless, restoration could benefit from low land rents. This is thought to provide an opportunity, especially in developing countries with low labor costs (GEF 2006). Indeed, small-scale biofuel production on degraded land has had a positive impact on energy provision in several developing countries. For example, in Mali, 1,000 hectares of jatropha plantations from "marginal" and unused lands provide oil for a local 300 kW power plant. This is expected to stimulate the local economy. The project required significant outside funding, however, to get started (Rijssenbeek & Togola 2007; MFC 2008).

Some of the areas currently classified as "marginal" may also in fact harbor high levels of biodiversity.

In some abandoned areas, the regeneration of natural habitats could be more beneficial from an environmental perspective than the establishment of biofuel crops.

There are still many uncertainties regarding the actual potential of use of degraded/"marginal" land for energy crop production. For many plants, like jatropha, there is a lack of quantitative productivity data from trials under sub-optimal conditions (Jongschaap et al. 2007). Specific crops that are being promoted as 'regenerators' of degraded land can have high water requirements and thus have a negative impact on surrounding vegetation (Chiavari 2008).

Some of the areas currently classified as "marginal" may also in fact harbor high levels of biodiversity. In some abandoned areas, the regeneration of natural habitats could be more beneficial from an environmental perspective than the establishment of biofuel crops. In any case, careful land evaluation has been recommended before conversion to biofuel cultivation (Fritsche et al. 2008). Further, in order to reach an economically viable level of productivity, high fertiliser application may be needed, increasing the risk for nutrient pollution. The performance thus critically depends on careful agricultural management. Another concern is related to the social impacts that could accompany biofuel projects in developing countries. Some degraded and "marginal" land is used by poorer households for biomass, building materials, fruit and nut collection and in some cases for subsistence crops (Sugrue 2008). Competition for land resources between biofuel producers and poorer groups may result in the latter losing access to the land on which they depend (Cotula et al. 2008).

The area of degraded lands potentially suitable for biofuel production is largely unknown. A GEF/UNEP/FAO/UNIDO project is currently underway to provide further guidance. As regards "marginal" land area, the Worldwatch Institute (2006) reported figures between 100 million and 1 billion hectares as theoretically available for energy crop cultivation, considering only that a lack of water and poor soil quality render the remainder uneconomical for energy crop harvesting. The FAO (2008) reported estimates between 250 and 800 Mha, excluding forestland, protected areas and land needed to meet increased demand for food crops and livestock, mostly located in tropical Latin America and in Africa. However,

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[32] Coastal management and seawater farms may be used for a combination of aquaculture and regeneration of mangrove forests (see for instance the "Greening of Eritrea", www.seawaterfoundation.org/video-eritrea.htm); cultivation of biofuel feedstocks could perhaps become a by-product.

the ability of "marginal" lands to significantly contribute to biofuel feedstocks has been questioned, especially as some of this land is de facto in use, although for non-cropping purposes, for example for livestock grazing (UN-Energy 2007).

Campbell et al. (2008) have recently argued that a substantial amount of land that could be used for biofuels is currently abandoned agricultural land. Their global estimate of abandoned land is between 385 and 472 Mha and they estimate that biofuels grown on this land could supply between 32 and 41 EJ/a (Fig. 6.3).

However, when forest is regrowing on abandoned land it may save more greenhouse gases to let the forest grow than to convert the land for biofuel production (Marland & Schlamadinger 1997; Righelato & Spracklen 2007). This depends on the amount of carbon released by clear-cutting and the saving potential of biofuels through substitution of fossil fuels in comparison to the amount of carbon naturally sequestered by the forest over time. Factors such as crop and fuel type, cultivation method, conversion efficiency to biofuels and natural growing conditions influence the climate change mitigation potential of both options.

Altogether, one may conclude that there is a certain potential to expand agriculture through the restoration of degraded land in order to produce biofuels, but possibly also food. This may also enhance rural development, in particular in developing countries. The global and regional potentials for adequate areas still need to be determined. Higher uncertainties regarding the potentials exist for "marginal land", which has never been under cultivation. In cases of abandoned land with high productivity (regrowing forests), the net environmental effect of biofuel production on climate and biodiversity would need to be assessed on a case by case basis.

When forest is regrowing on abandoned land it may save more greenhouse gases to let the forest grow than to convert the land for biofuel production.

Figure 6.3: **Worldwide potential of abandoned land**

Source: Campbell et al. (2008)

6.3. Using biomass for power and heat

Using biomass for power and heat is generally more energy efficient than conversion to transport fuels.

Stationary use, for example to generate electricity for local use, is generally more energy efficient than converting biomass to liquid fuels. It is also thought to have the potential for much higher CO_2 savings at lower costs.

For example, 1 MJ of biomass may replace about 0.95 MJ of fossil fuel in heat and electricity production, whereas 1 MJ of biomass can only replace about 0.35-0.45 MJ of crude oil in the transport sector. This is because modern biomass burners are nearly as efficient as fossil fuel burners (Edwards et al. 2008). The gasification of biomass for electricity (and/or heat) is capable of saving more CO_2 emissions per tonne of biomass (or per hectare) than conversion to conventional transport fuels (Edwards et al. 2007).

Both energy crops and/or wastes and residues may be used as feedstocks for stationary technologies (Table 6.1). They are applicable at different scales and may provide various benefits, particularly for local communities. In developed countries, these can include cutting-edge technology and multifunctionality, for example by combining waste treatment with energy provision. In developing countries, stationary use has been shown to enhance liv-

Table 6.1: Generic overview of performance projections for different biomass resource – technology combinations and energy markets on shorter (~5 years) and longer (>20 years) timeframes

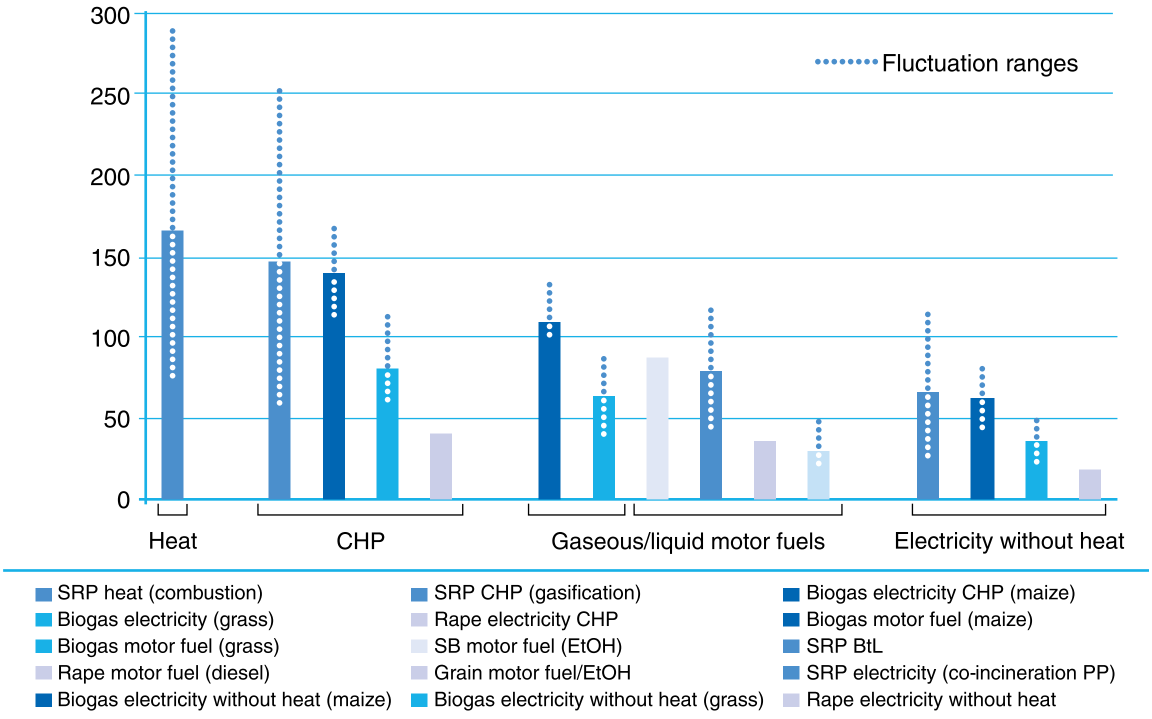
Biomass resource	Heat		Electricity		Transport fuels	
	Short-term; stabilising market	*Longer term*	*Short-term; strong growth market worldwide*	*Longer term growth may stabilise due to competition of alternative options*	*Short - term; growing market but highly policy driven*	*Longer - term; potential key market for cultivated biomass*
Organic wastes (i.e., MSW etc.)	Undesirable for domestic purpses (emissions); industrial use attractive; in general competitive.	Especially attractive in industrial setting and CHP (advanced combustion and gasification for fuel gas).	<€$_{ct}$ 3-5/kWh for state-of-the-art waste incineration and co-combustion. Economics strongly affected by tipping fees and emission standards. Landfill gas recovery and utilisation is generally a competitive utilisation scheme.	Similar range; improvements in efficiency and environmental performance, in particular through IG/cc technology at large-scale.	n.a.	In particular possible via gasification routes (see below).
Residues: • Foresty • Agriculture	Major market in developing countries (<€$_{ct}$ 1-5 / kWhth); stabilising market in industrialised countries.	Especially attractive in industrial setting and CHP. Advanced heating systems (residential) possible but not on global scale.	€$_{ct}$ 4-12/kWh (see below; major variable is supply costs of biomass); lower costs also in CHP operation and industrial setting depending on heat demand.	€$_{ct}$ 2-8/kWh (see below; major variable is supply costs of biomass)	n.a.	€ 5-10/GJ; Low costs obtainable with lignocellulosic biomass (<US$2 / GJ) advanced hydrolysis techniques and large-scale gasification (i.e., <1000 Mwth) for MeOH/H_2/FT, as well as improved sugar cane production and subsequent ethanol production in optimised distilleries.
Energy crops: • oil seeds • sugar/starch • sugar cane • perennial crops (i.e., short rotation cropping trees and grasses)	n.a.	Unlikely market due to high costs of feedstock for lower value energy carrier; possible niches for pellet or charcoal production in specific contexts.	€$_{ct}$ 5-15/kWh High costs for small-scale power generation with high-quality feedstock. Lower costs for large-scale (i.e.,. 100 MW th) state-of-the-are combustion (wood, grasses) and co-combustion.	€$_{ct}$ 3-8/kWh Low costs especially possible with advanced co-firing schemes and BIG/CC technology over 100-200 MWe.	€ 8-25/GJ; Lower figures for ethanol from sugar cane; higher for biodiesel (RME) and sugar and starch crops in Europe and North America.	

Source: IEA Bioenergy 2007 (adapted from WEA 2004; IEA 2006b; Faaij 2006; IPCC 2007; Knoef 2005: van Loo and Koppejan 2002) ing conditions with household cooking stoves and community-wide electrification. Particularly, biogas has large potential as a renewable energy source with good GHG savings, especially when waste is used. When maize is used, the energy yield per hectare is higher than for transport fuels, but still raises environmental and land use concerns.

As stationary use encompasses a wide span of both technology and feedstocks, delving into all available applications is beyond the scope of this report (see Table A.1 in the appendix for an overview). Figure 6.4 compares common applications and feedstocks in Germany from a land use perspective. As shown, heat and combined heat and power (CHP) applications are capable of generating more energy per hectare than conversion to liquid fuels. As a result of this high efficiency, CHP appears well suited to conditions where both heat and electricity are needed.

In addition to higher land use efficiency, stationary use may also have larger potential to mitigate climate change. Conventional generation of electricity is carbon and energy intensive, resulting in good potential to 'save' CO_2 through biomass substitution. This is especially the case in most European countries, or countries with a relevant

Figure 6.4: **Overview of current energy yields (net) of renewable raw materials for different usage paths in GJ/ha**



Notes:

Using Miscanthus (zebra grass) results in yields that are about 20% higher than SRP, but this possibility is not considered here because the technology is not yet commercially viable.

In the case of heat, CHP, and power (without heat), the utilisation efficiencies are included; in the case of motor fuels only the production losses, but not utilisation losses, are included. Thus the data can only be compared to a limited extent; use of the fuels in motor vehicles will reduce the energy yield still further.

SRP = short- rotation plantation, BtL = biomass-to-liquid, PP = power plant, CHP = combined heat and power, EtOH = ethanol, SB = sugar beet.

Source: SRU 2007 (adapted from LFU 2004: Arnold et al. 2006; DENA 2006; FNR 2005b: 2005a; 2006a; Keymer & Reinhold 2006; Schindler & Weindorf 2006) share of fossil fuel supply which can be replaced[33]. Production of wood with subsequent gasification, for instance, may save more than twice as much GHG emissions when used as a substitute for coal in stationary use rather than producing bioethanol or biodiesel from any biomass for the transport sector. Direct hydrogen production from wood may also be an attractive option, but this technology is still under development (Edwards et al. 2007). From the available data, one may also conclude that as long as wood can be used to substitute fossils for power and heat generation with state-of-the-art technology, BtL from wood will not be able to save more GHG emissions.

Moreover, the typical cost of saving one tonne of CO_2 equivalent in 2020 may be well over Euro100 for both first- and second-generation biofuels in the EU, while the cost of replacing a given amount of oil with solid biomass may be much less than half of that (Edwards et al. 2008). However, feedstock costs are still higher than their fossil fuel counterparts in the EU. Electricity from biogas, for instance, is roughly two to four times more expensive than current fossil options (Graebig et al. 2009).

Using biomass for local power supply could improve living conditions in developing regions.

In comparison to biofuels for transport, which require medium-scale facilities for economic viability, stationary use can be applied at the local level and thereby exploit dispersed resources from both agriculture (energy crops, manure) and households (sewage treatment plants). It can be used at more locations and is suitable for a wider variety of applications, which may be particularly relevant in regions without electricity. Building a basic supply of decentralised power generators, for example, could provide a substantial improvement to community living conditions. In contrast, biofuels for transport benefit national or international markets far from production sites. Thus, stationary use in developing countries may provide additional value by providing locally produced sustainable energy.

In developing countries, stationary use of biofuels may also substitute traditional biomass, which is often burned inefficiently for heating and cooking. This type of substitution could be a goal for bioenergy implementation and a measure to overcome energy poverty (WBGU 2008). The improved access to energy in developing countries is spurring new businesses. Health conditions, especially for women and children, can also be improved through such measures (UN-Energy 2007). For instance, in the Philippines a cooking stove which can be run on plant oils (such as jatropha, peanut, sunflower and used cooking oil) has been developed. A public-private partnership provided initial financing to a local coconut oil production cooperative of 400 Philippine families. The cooperative has managed to achieve a 20% increase in revenue and kept the cost of coconut oil below that of kerosene—although kerosene is subject to higher taxes (BSH 2008).

Small to medium-sized applications have shown that stationary use of biofuels can support power and heat supply of rural communities. Heat and electricity generation from forestry is common for example in Sweden and Finland.

Biogas is an example of stationary use, which when implemented and managed properly, seems to hold promise for energy provision and GHG reduction. Biogas from residues, waste and manure provide mostly benefits. However, land use may be a relevant concern when facilities are fed with energy crops such as maize. For instance, in Germany more than 3,750 biogas facilities provide decentralised heat and electricity into the grid, as well as treatment of livestock excrement. The number of facilities has boomed recently, due to subsidisation by feed-in tariffs. Most plants operate on a scale between 70 und 500 kWe and 47% and 41% of the substrates fermented on average are energy crops and excrement respectively. Organic waste comprises 10% and industrial and agricultural wastes compose the remainder (IE 2008). As energy crops, mainly maize is used (IFEU 2008), and maize-to-biogas yields more than three times as much energy per hectare as grain-to-ethanol (see Fig. 6.4). Maize for biogas, however, increasingly competes with maize for cattle feed, and growing demand may significantly contribute to Germany´s domestic and global land use (Bringezu et al. 2008). In contrast, biogas from wet organic waste, in particular manure, does not require extra land. Moreover, biogas from manure

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[33] For instance, China is using a large amount of coal for power generation, which provides potential for substitution by biomass; in contrast, Uganda uses mostly renewable energies, such as hydropower, which potentially makes substitution of fossil fuels in the transport sector a better opportunity (WBGU 2008); nevertheless, using local biomass (e.g. from residues) for power supply in off-grid areas while exporting hydropower from dams to neighbouring regions could also be an option to improve the overall GHG balance on a larger scale.

saves ten times more GHG emissions (5.5 vs. 0.5 kg CO_2-eq) per cubic meter methane produced than from energy crops (Wuppertal Institute et. al 2005). The management of the facilities is also important. For instance, 65% of the biogas producing facilities built in Germany since 2004 are either uncovered or improperly sealed, so methane is escaping to the atmosphere and can actually be contributing to climate change rather than mitigating it (IFEU 2008).

In conclusion, stationary use of biomass for energy conversion to heat and electricity can provide significant advantages compared to biofuels for transport. Various stationary applications provide higher energy yields and benefits for GHG mitigation than use for transport. When stationary use is based on energy crops, the extent of land use and the quality of crop production determine the resulting environmental impacts. In contrast, use of residues such as manure to produce power and heat provides multiple benefits.

6.4. Use of waste and production residues

The energetic use of wastes and residues could provide the double benefit of waste management and energy provision. The potential of waste and residues as feedstocks for stationary use has been well documented. Second-generation technologies, when these become available, may also be able to make use of residues. From an environmental perspective, they have no direct land-use requirements, but emissions from waste incineration and the amount of residues which could be sustainably removed from the forest or field, remain concerns.

Wastes currently relevant for energy generation are municipal solid waste (MSW) and animal and food wastes (Gill et al. 2005). Relevant residues include those left on the field or in the forest after harvest and the leftovers of processing, such as bagasse, black liquor and sawdust.

However, a few constraints need to be overcome before waste and residues can realise their full potential. From an ecological perspective, emissions from combustion can be hazardous when the feedstock has a high heavy metal content, for example when it stems from phytoremediation. Agricultural residues contain nutrients and maintain soil carbon content and fertility—which is why they are often left on the field. They also provide protection against erosion, can contribute to soil biodiversity, and may even provide a habitat for wildlife. In particular with regard to nutrient cycling and soil protection, it is uncertain what fraction of residues can be removed. Recycling of nutrients is also a largely unresolved issue for waste incineration. More research is needed to clarify these questions for various feedstocks and processing routes.

Residues and organic wastes could supply between 40 and 170 EJ/a to bioenergy use globally (IEA 2007b), although the recent WBGU (2008) report estimates a sustainably usable potential of 50 EJ per year. Altogether they could provide a larger energy resource than bringing "marginal" land into production for biofuels. Regional studies have indicated the potential of utilising residues and waste streams. For instance, Edwards et al. (2005) explored the theoretical possibility of implementing straw-based power plants in the EU-27, showing 21 TWh of electricity at costs of 68 to 73 Euros/MWh to be theoretically possible.

Altogether, considerable potentials for energy recovery from municipal organic waste and residues in agriculture and forestry exist. Promising examples show that various technologies for energy recovery are available and being further developed to enhance efficiency. Research is required in particular with regard to the proper balance of residues remaining on the field for soil fertility and removal for energy, as well as with regard to nutrient recycling and pollution control after energy recovery.

The energetic use of waste and residues could provide the double benefit of waste management and energy provision. However, removing agricultural residues has an opportunity cost as they help maintain soil carbon content and fertility and protect against erosion.

Box 6.1: Combining wastewater treatment with energy provision

In Sweden, willow energy plantations are being used in cross-cutting applications for both wastewater treatment and energy. For example, the Enko CHP plant has an efficiency of 90%, produces 45 MW of heat and 24 MW of gross electricity, and utilises the 150 hectares of willow plantations planted within 30 kilometers of the plant. Roughly 15% of the feedstock is Salix (with wood chips, saw dust and bark comprising 50%, 15% and 20% respectively) (Wright 2006). The majority of the willow plantations are multifunctional, also serving as filters for municipal wastewater. This appears to provide the plantations with nutrients—both alleviating the need for fertiliser and reducing pollution of sewage treatment (Boerjesson and Berndes 2006).

Box 6.2: Winning energy from wastes and residues

MSW can be incinerated, for example generating 6,650 GWh of electricity in Germany annually (BMU 2008). This reduces the need for landfilling. Whereas incineration is the prefered route for dry organic waste like wood (e.g. from bulky MSW), biogas is usually produced from wet organic waste (e.g. kitchen and garden waste). In the UK, 2.5 million tonnes of MSW (about 9% of the MSW produced annually) are combusted to provide, along with sewage sludge digestion, 0.7% of the country's electricity. However, the majority of waste is still landfilled, and even a significant amount of wood waste is being sent directly to landfill. This could readily amount to 3 million tonnes/year and could generate up to 8.5 TWh of heat, with corresponding carbon savings of 0.85 million tonnes carbon (Gill et al. 2005).

Agricultural and forestry residues can also be used. In the UK, Ely is home to the world's largest straw burning power plant, with a capacity of 38MWel. The Ely power plant consumes 200,000 tonnes of straw yearly from a 50 km radius (Edwards et al. 2005). In Finland, the district heating plant of Kokemäen Lämpö Oy, opened in 1998, is fueled by sawdust, woodchips, commercial waste and peat, thus potentially reducing the critical use of the latter, and sold 25.8 GWh of heat in 1999 (OPET/VTT 2001).

Energy may also be won from production residues. In Brazil, bagasse generated 3 GW of electricity in 2007, or about 3% of the total energy matrix (Frost & Sullivan 2008).

6.5. Cascading use of biomass

Using biomass as a production material first, then recovering the energy content from the resulting waste, can provide multiple benefits. Biomass use may be further improved by recycling it several times before a final energetic utilisation at the end of its lifecycle. Such cascading systems may provide general advantages for climate change mitigation and land use.

A comparative LCA study indicated that the use of biomass for material production causes less environmental pressure than use for transport biofuels. Based on the selected cases studied, bio-based commodities showed the highest variation and potential for environmental relief through the substitution of fossil based products. Heat and electricity supply are also shown to be better for the environment than transport biofuels (Weiß et al. 2004) (Fig. 6.5).

The combined material and energetic use, as in a cascade, can maximise the CO_2 mitigation potential of biomass. Through reutilisation it is possible to displace more fossil fuel feedstock with a smaller amount of biomass (UN-Energy 2007). Cascading systems may also be more efficient in terms of land use. Multiple applications of the original biomass can reduce requirements and thus the competition for land.

However, competition between energetic and material use may be an obstacle for the prolongation of cascading chains. Forestry, pulp and paper products in Germany, for instance, have already experienced competition with saw dust, wood pellets and chips for energy use, partly as a result of the financial support for bioenergy applications (Bringezu et al. 2008b).

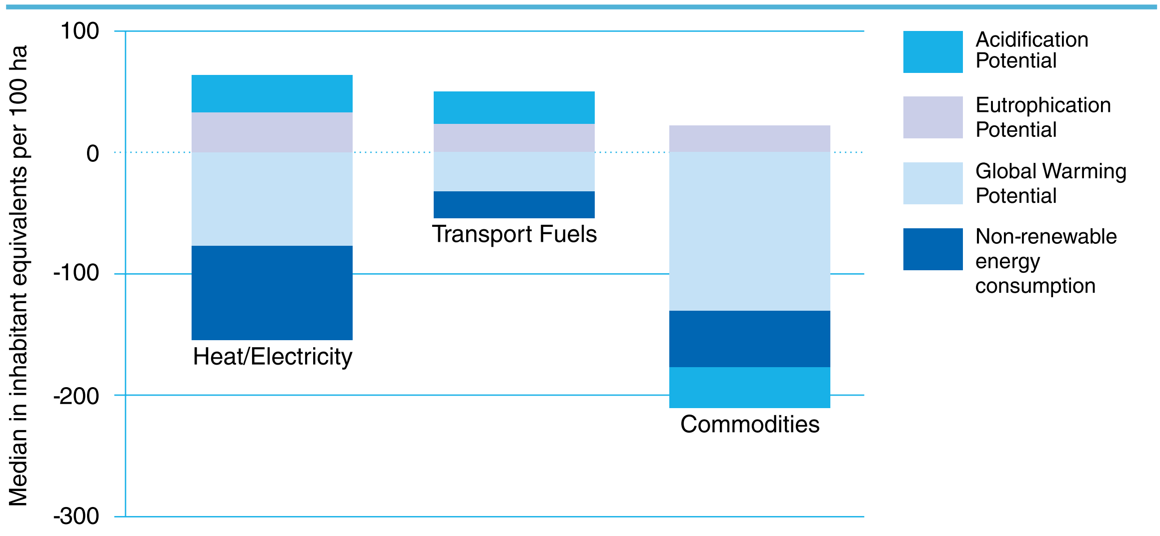
Biomass use may be further improved by recycling it several times before a final energetic utilisation.

Nevertheless, the use of cascades can assist in the innovation of bio-based production processes, which advance the economy towards fossil fuel replacement (Ignaciuk 2006). While furniture, building frames, packaging, clothing, and paper are already significant biomaterials, bio-based plastics and fabrics are likely to become more important in the future. The Worldwatch Institute (2006) expected that demand for biomass as a material feedstock in the long term may surpass the historic demand for biomass as a source of energy.

Biomaterials are often superior to biofuels with regard to environmental performance as substitutes for fossil based products.

As long as biomaterials are derived from agriculture and forestry, they require land and are dependent on feedstocks, putting them in competition with food and biomass for energy. The ongoing increase of production of biomaterials may reach between 10 and 11% of the overall land requirements for the consumption of agricultural goods in Germany by 2030 (Bringezu et al. 2008). Therefore, although biomaterials are often superior to biofuels with

Figure 6.5: **Comparative relief of environmental pressure through use of biomass for heat/electricity, transport fuels and material products**



*Note: medians of normalized differences between alternative uses of biomass vs. traditional fossil fuel use are shown. Negative values indicate advantage of biomass products.

Source: Weiß et al. 2004

regard to environmental performance as substitutes for fossil based products, increased demand may result in similar pressure on land use as biofuels.

Although cascading tends to mitigate the competition between different types of biomass use, few comprehensive analyses of cascading systems have been made. Dornburg and Faaij (2005) developed a bottom-up approach for analysing cascades, considering the influence of the system boundaries, the inclusion of (indirect) land use and the inclusion of a time dimension. However, their results are only valid for a small-scale cascading chain application.

Technolgies such as photovoltaics (PV) and solar thermal power do far better; already, they can make use of 9 to 24% of the radiation input; and can be installed on roofs and facades, which requires no additional land.

Further research is required to determine the full potential of bio-based materials with regard to sustainable resource use and environmental performance, considering the whole range of biomass use (food, fibre, plastics, fuels). Research is also required for providing appropriate information for policy makers to make better use of cascading potentials by applying proper policy instruments.

6.6. Mineral-based solar energy systems

Biomass and photovoltaic technology both make use of the solar radiation reaching the surface of the earth. However, biomass in the open field can generally store only about 1 to 6% of the solar radiation input (Woods et al. 2009), which still requires transformation into useful energy. Whereas technologies such as photovoltaics (PV) and solar thermal power do far better; already, they can make use of 9 to 24% of the radiation input, with recent averages of about 15% (Green et al. 2007; WEC 2007; Lightfoot & Green 2002). Further, solar systems can be installed on roofs and facades, which practically requires no additional land. In contrast, biomass has the lowest power density of all renewable energies, and therefore requires the largest amount of land.

Beyond greater land use efficiency, solar systems may also provide more environmental benefits than biofuels. In Germany, PV is superior to biogas (from maize) per electric energy output regarding fossil energy consumption and acidification, and can mitigate about 4 times the amount of GHG emissions. Eutrophication, interestingly, is higher for PV than biogas (Graebig et al. 2009)[34]. Research is ongoing and further required to reduce the environmental burden of PV systems, also to reduce the use of hazardous and resource intensive substances and improve recycling.

In comparison to energy from biomass, solar energy is currently subject to a cost disadvantage. In the long-term, however, the cost of solar energy is expected to decrease considerably and may be more competitive with biomass. Decentralised generation by solar PV is already shown to be economically feasible for rural villages with long distances to a distribution grid. Further, using solar thermal energy for heating and cooling is increasing, with China comprising 80% of the annual global installations for glazed domestic solar hot-water systems.

Solar energy applications can substitute 'traditional biomass use' in developing countries and provide community electrification. For instance, solar cookers are gaining widespread use, especially in developing countries. More than 2.5 million households in developing countries were receiving electricity from solar home systems by 2007, with most of these located in Asian countries (REN21 2008)[35].

In summary, alternative technologies are available which can provide power and heat with more efficient land use and potentially less environmental impacts than the most efficient utilisation of biomass. Investing in the research and development of those technologies will help render them more competitive in economic terms and improve their environmental performance further. Solar technologies are already in use, and are already economically viable in off-grid locations. As these technologies provide services similar to biofuels, their adequacy should be determined in the local socio-cultural, economic, technological and environmental context.

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[34] Further research is necessary to analyse the reasons and options for improvement.

[35] see also UNEP Fact Sheets: http://www.unep.fr/energy/information/publications/factsheets/pdf/pv.PDF and http://www.unep.fr/energy/information/publications/factsheets/pdf/thermal.PDF

Box 6.3: Solar energy is more land efficient than bioenergy

Systems based on solar power provide higher energy yields per hectare than biomass. For example, an excellent harvest of Iowa corn (yielding 12t/ha of grain and the same amount of stover) and intensively harvested short-rotation crops, such as willow (with 20t/ha of dry matter), both have an average power density of 1.1 W/m^2. Conversion to useful energy renders a lower per area energy density. Considering high efficiencies of 55-60% for converting biomass to methanol or alcohol and over 50% for heat and electricity cogeneration, final energy supply will yield 0.5 to 0.6 W/m^2. In contrast, under the best conditions and in the sunniest sites, solar to electric conversions could have peak power densities of around 60 W/m2, although less sunny locations are closer to 40 W/m^2 and trough systems in the Mojave Desert have peak power generation densities of less than 15 W/m^2 (Smil 2003).

Box 6.4: Alternative options for providing rural areas in developing countries with modern energy

‘Switch On’ is an example of a rural housing energisation project in KwaZulu Natal, South Africa, which demonstrates a user-owner model of non-grid energy provision to rural communities. A local company, ‘Switch On’, was established to finance and maintain energy packages for community members. The energy package included a solar home system and a stove with bottled liquefied petroleum gas. This has substituted the use of wood, and emissions from fires and deforestation have been reduced as a result. Improved access to credit and banking facilities have also benefited the community (Wisions 2006).

Section 7: Strategies and measures to enhance resource productivity

A plethora of biofuel policies have recently emerged. Through various mechanisms of support, governments have propelled the development of chiefly national biofuel programmes. Standards, increasingly introduced to address sustainability concerns, can contribute to the sustainability of feedstock cultivation and biofuel production, but may be ineffective at controlling indirect land use change and overall cropland expansion. Moving forward, broader strategies to foster sustainable land and resource use are needed. Measures to increase agricultural yields and limit the expansion of cropland may contribute to a more efficient use of land. Various policies can help to use biomass more efficiently. Moreover, improving the productivity and reducing the consumption of resource use (both biotic and abiotic) in transport, industry and households seems to be a key prerequisite for adjusting biomass use to levels which can be supplied by sustainable production.

7.1. Recent transport biofuel policies

Many countries have turned to biofuel development in an attempt to secure an energy source for the future, promote rural development and combat climate change. For this reason, biofuel development has largely been characterised as national efforts and a wide range of policies from multiple sectors have emerged. Mandates and targets have fuelled development, but as negative environmental consequences of biofuels have come to light these have come under scrutiny as being insufficiently supported by science. It is outside the scope of this report to assess major policies in detail, instead a few shortcomings of existing measures will be highlighted. In doing so, it complements other recent assessments of biofuel policies (see for example, IRGC 2008, Decision COP/9/L.35 under the Convention on Biological diversity, and FAO 2008).

While biofuel policies have been, in part, developed to mitigate climate change, measures effectively ensuring climate change mitigation seem to be lacking. Most policy measures do not differentiate between biofuels according to their potential to reduce greenhouse gas emissions, which seems largely contingent on the type of feedstock and its crop management (as shown in section 4). Sustainability standards and certification are now being developed in order to ensure at least minimum improvements of biofuels compared to fossil alternatives. While this may improve the environmental performance of selected product chains ("vertical" dimension), it may not be sufficient to ensure sustainable land use patterns if increasing demand leads to the expansion of cropland ("horizontal" dimension).

As biofuels generally face much higher costs than fossil fuels, governments have largely approached biofuel development with a wide variety of support mechanisms aimed at reducing this disadvantage[36]. These subsidies, grants, tariffs, tax exemptions, and various other incentives and preferences have driven development of energy farming and a biofuel industry.

It should also be noted that fossil fuels also receive substantial direct and indirect subsidies. UNEP (2008b) estimates that worldwide subsidies for energy might amount to $300 billion per year. Abolishing subsidies and liberalising all fossil fuel trade would cut GHG emissions by about 6%, according to a 2000 OECD report.

The OECD (2008) estimates support to the US, EU, and Canadian bioethanol and biodiesel supply and use in 2006 at about US$ 11 billion, projected to rise to US$ 25 billion over the medium term. Biofuels tax exemptions and/or incentives exist in at least 10 EU countries, Argentina, Bolivia, Brazil, Colombia, Paraguay and South Africa (REN21 2008). For instance, in Brazil, exemptions from excise tax

Broader strategies to foster sustainable land and resource use are needed.

Sustainability standards and certification, developed in order to ensure at least minimum improvements of biofuels compared to fossil alternatives, may not be sufficient to ensure sustainable land use patterns if increasing demand leads to the expansion of cropland.

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[36] Brazilian ethanol production comes closest to commercial viability and has become competitive with petroleum based gasoline on world markets in recent years (Goldemberg 2007). However, others argue that sugar cane ethanol would not be economically viable without still existing exemptions of excise duties within Brazil (De Almeida et al. 2007; OECD/ITF 2007).

and reduced VAT for ethanol were estimated by De Almeida et al. (2007) to amount to US$ 977 million per year.

The costs to mitigate climate change with transport biofuels seem extraordinary. Subsidies in the U.S., Canada and the EU exceed the carbon value at European and U.S. carbon markets, indicating that technologies in other areas of energy use are available which reduce GHG emissions much more economically.

The costs to mitigate climate change with transport biofuels seem extraordinary. Doornbosch & Steenblik (2007) estimated that subsidies of biofuels would roughly double the cost of transportation energy for consumers and taxpayers together in most cases. According to OECD (2008), subsidies in the US, Canada and the EU cost taxpayers and consumers on average between US$ 960 and 1,700 per tonne of CO_2eq avoided in those countries. This level far exceeds the carbon value at European and US carbon markets, indicating that technologies in other areas of energy use are available which reduce GHG emissions much more economically and underlining the priority governments give to energy security.

As a result of trade barriers and the high concentration of relevant biofuel production within only a few countries, trade has been limited so far. Brazil exported more than half of the ethanol traded globally and the U.S. imported more than half of the world-traded ethanol in 2006. Indonesia and Malaysia are the major exporters of biodiesel, with the EU the major importer (OECD 2008). The leading OECD countries producing ethanol apply most-favoured nation tariffs that range between 6 and 50%. Biodiesel tariffs are lower, with ranges between 0 and 7%. Developing countries apply tariffs that typically range between 14 and 50% (Steenblik 2006; Doornbosch & Steenblik 2007). Many non-tariff barriers to trade also exist, such as public health and safety regulations and technical characteristic requirements of liquid transport fuels. However, biofuel trade is expected to grow as a result of targets, which will not be able to be met with domestic production in most countries and are expected to stimulate production in other regions of the world.

According to the OECD (2008) the elimination of import tariffs for biofuels could have significant effects on the amount of GHG emissions avoided via biofuels. Such a measure would reduce the production of grain- and sugar-beet-based ethanol more than the increase in sugar cane-based ethanol. Due to higher specific GHG reduction rates for cane ethanol, GHG avoidance would increase by between 3.5 and 6 Mt of CO_2eq per year. These gains would have to be balanced against potential emissions from additional land use change. In Latin America about 0.8 Mha would additionally go into crop production, with a potential release of some 44 Mt of CO_2eq. On the other hand, lower cereal and oilseed prices would reduce the area expansion in Asia and Africa by more than 1 Mha, potentially offsetting the increased land use in Latin America. The OECD concludes that more in-depth analysis about the land types affected in different regions is necessary to assess the impact that land use changes could have on global GHG emissions. One may assume that this also applies to other impacts, such as on biodiversity.

7.1.1. Production standards and product certification

The diverse range of biofuel-sector stakeholders, and growing concerns about unintended side-effects, have led to efforts to promote more sustainable bioenergy development (Doornbosch & Steenblik 2007; UNCTAD 2008; Dam et al. 2008; Lewandowski & Faaij 2004). Currently, at least 29 initiatives are being led by national agencies, NGOs, and associations to create, verify, and certify performance standards for the sustainable production of biomass and biofuels. These standard setting and certification initiatives range from national to international schemes, related to a specific sector such as sustainable forestry, organic agriculture, and sustainable biomass production. Table 7.1 details some certification and performance standard initiatives.

Of those countries with blending targets and mandates, only a few have implemented sustainability components into production requirements and life cycle standards. These standards use market and policy mechanisms and target both social and environmental indicators (Table 7.2).

The number and diversity of sustainability schemes and initiatives calls for harmonisation. It has been suggested that in an era of global trade, only international certification schemes will ensure environmental aims. The international context, for instance, is the red thread running through the suggestions for a sustainable biomass framework from the Cramer Commission (2007), which also underlines the importance of international cooperation to the feasibility of such a framework, especially for verification and enforcement. Certification based on life-cycle-wide criteria improves transparency along the production chain. Production standards may also improve the environmental and social performance of products. However, market-based product certification usually only covers a fraction of the product market (Sto et al. 2005; Liu et al. 2004). This may impose the risk of creating the appearance of sustainable production by some, while others may continue unsustainable production (Doornbosch & Steenblik 2007).

Market-based product certification usually only covers a fraction of the product market.

Table 7.1: Certification schemes and performance standards for the production of biomass and biofuels

	Affiliation					Sector				Scope			Criteria		
	NGO	National Government	Inter-Governmental	Private	Multi - sector	Forestry	Agriculture	Biofuel	Trade	National	Regional	nternational	Environment	Social	Economic
Certification															
Australian Forestry Standard		●				●				●			●	●	●
Canadian Standards Association - Sustainable Forest Management	●					●				●			●	●	●
Forest Stewardship Council – P&C Standard	●					●			●			●	●	●	●
Green Gold Agriculture/Forest Label (standard when no certification system is available)	●			●		●	●					●	●	●	●
Indonesia Eco-labeling Institute-Sustainable Forest Management	●					●				●			●	●	
International Federation of Organic Agriculture Movements – IFOAM Accreditation Criteria	●			●			●		●			●	●	●	●
Naturland Association for Organic Agriculture - Standards	●					●	●			●		●	●	●	
Rainforest Alliance – Sustainable Agriculture Network	●						●					●	●	●	●
Performance standards															
Climate, Community & Biodiversity Alliance (CCBA) – CCB Standard	●			●		●	●	●				●	●	●	●
Fairtrade Labelling Organization – Fairtrade standards	●						●		●			●	●	●	●
International Standards Organizations (biofuel standard in development)	●							●				●	●	●	●
Netherlands – Agency for Energy & Environment (currently discussing certification of biofuels)		●						●		●			●	●	●
Roundtable on Sustainable Biofuels (RSB) – Sustainability standards					●			●				●	●	●	●
Roundtable on Responsible Soy					●		●					●	●	●	●
Roundtable on Sustainable Palm Oil					●		●	●				●	●	●	●
Sustainable Forestry Initiative	●			●		●				●	●		●	●	●

Note: This table only includes some key certification and standards for bioenergy, although not all are shown

Source: after compilation by UNEP-DTIE

Table 7.2: **Initiatives to enhance sustainability of biofuels**

	Sustainability initiatives
Brazil	'Social Fuel Seal' certification program by the Ministry of Agriculture
European Union	Directive on Renewable Energies – comprehensive requirements for biofuels accountable for mandatory quota
Germany	Biofuel Quota Law- Ordinance for sustainability requirements
India	All bioenergy crops to be grown on 'waste lands' or unsuitable soils for traditional agriculture
South Africa	Target excludes maize for food security concerns
United Kingdom	Targets producers to report GHG savings and environmental impacts of biofuel production, possibly leading to voluntary certification
United States	Based on a crediting scheme, the RFS creates a market incentive to promote second generation ethanol production for greater resource efficiency

Source: after compilation by UNEP-DTIE

While product standards may alleviate some of the environmental concerns of biofuel production, other problems remain. None of the schemes aimed at certifying international biofuel trade have yet been tested, especially in conjunction with government support schemes, such as subsidies, under international trade agreements (Doornbosch & Steenblik 2007; UNCTAD 2008; FAO 2008). In the case of ecolabelling schemes, it has been shown that their introduction could – under some conditions – cause negative effects on the environment because of the rebound effect (Bougherara et al. 2005, Geibler 2007).

Developing countries have also considered certification and labeling to be ‘green imperialism’ as it restricts them from profiting from their comparative advantage in natural resources. Mol (2007) has argued that harmonisation, standardisation, certification and globalisation of biofuel pathways will empower large organised actors with the means of operating beyond regional networks. But developing states, farmer cooperatives and localised NGOs do not appear to be empowered by an increasingly globalising scope, as their power in these networks is limited. Initiatives to protect small-scale farming and local small biofuel businesses include the social label in Brazil, which is designed to benefit small-scale farming in large-scale biofuel production. In the absence of such initiatives, free market conditions would render large-scale farming more competitive than small-scale farming of transport biofuels.

Initiatives to protect small-scale farming and local small biofuel businesses are needed to ensure their competitiveness.

Certification schemes, even if ambitious, are usually based on a limited set of life-cycle wide criteria. As a consequence, certain problems may be neglected or shifted in the course of subsequent applications. For example, in the recent EU directive on renewable energies, which includes minimum standards for accountability of biofuels, fertiliser use has hardly been mentioned (EU 2009b). Although the Commission´s methodology accounts for on-site N_2O emissions during agricultural production, it remains uncertain in how far the nitrogen that is leached to ground and surface water - leading to pollution and subsequent off-site N_2O emissions - will be considered[37]. This demonstrates the complexity of issues facing certification and portrays the uncertain environmental consequences which could emerge from targets that have not, or have only partially, been examined with life-cycle-wide criteria (Eickhout et al. 2008).

An inherent problem of biofuel certification is how to control the expansion of land used for agriculture. Prohibiting expansion of biofuel cropland on high value natural ecosystems does not necessarily mean that farmers could not plant food crops in these high value areas and use the old cropland for biofuels (Searchinger 2009). As the impacts of land expansion from fuel or food crops are indistinguishable, it could be argued that equal standards should

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[37] Art. 17 (7) requires the European Commission to report on national measures taken for soil, water and air protection.

be applied for all agricultural commodities (FAO 2008). More research is needed to account for the risk of indirect land use change of specific biofuels to GHG mitigation. As the risk of indirect effects depends on the overall demand for biofuels and other biomass products, product specific approaches to define GHG emissions, such as "risk adder" (see Fritsche 2008b), would have to be complemented by projections on the country or regional level. Thus, the performance of both the consuming country/region and the product/production on a global/life-cycle-wide basis should be considered.

As the risk of indirect effects from land use change depends on the overall demand for biofuels and other biomass products, sustainability standards should be applied for all agricultural commodities. Alternatively, product specific approaches should be complemented by projections on the country or regional level.

In order to help prevent indirect land use change, certification schemes should ideally be applied globally to imports of all biomass products (Edwards et al. 2008). As this seems highly unrealistic, product certification schemes for biofuels are unlikely to be sufficient to control the expansion of cropland due to increased demand (Edwards et al. 2008; Searchinger 2009). For that purpose, additional instruments are needed.

7.2. Fostering sustainable land use for biomass production

Enhancing agricultural productivity will be required for and may benefit both food and non-food production. Intensification as well as expansion of cultivation could be directed to promising areas and balanced with environmental and social concerns.

7.2.1. Increasing agricultural yields in an environmentally benign manner

Increasing agricultural yields is of paramount importance to both feeding the world population and meeting the increased demand for biofuels. This topic is beyond the scope of this report, which focuses on the biofuel dimensions of the challenge. Key is mobilising potentials in regions where productivity increases have lagged, such as sub-Saharan Africa. To this end, a bundle of measures (investments into infrastructure, education and training among others) are required to overcome current constraints. These are being developed very slowly for food crops, but the recent accelerated foreign investment in biofuel crops may lead to broader progress. Although the benefit for the local population remains uncertain - China, for example, is sending farmers to grow crops in Africa[38], but the amount of production which will remain in Africa compared to that which will be imported to China is unclear. A promising initiative is the policy of the German company Flora Eco Power, which leases land in Ethiopia for castor and jatropha oil production, eschewing land usable for food production, and actively involves Ethiopian farmers.

Key is mobilising potentials in regions where productivity increases have lagged.

As all those activities tend to lead to intensified and expanded agriculture, the environmental and social impacts will have to be monitored carefully in the future.

7.2.2. Limiting expansion of arable land and directing new fields to degraded land

Any cropland expansion, whether for food or non-food purposes, should not occur at the expense of valuable ecosystem services and high value natural ecosystems, such as forests and areas of high biodiversity. Various mechanisms are under development to shelter such lands, for example by providing them with an economic value (such as Reduced Emissions through Degradation and Deforestation programmes and the Convention on Biological Diversity activities, see also TEEB (The Economics of Ecosystems and Biodiversity) 2008). First, GIS based inventories have been established to monitor the biodiversity together with the carbon stocks of the vegetation, in order to support priority setting for conservation measures (Kapos et al. 2008).

Any cropland expansion should not occur at the expense of valuable ecosystem services and high value natural ecosystems.

Zoning is another method, which is currently being employed in some regions of Brazil like the Amazon. Agro-ecological zoning can be used to distinguish land with the potential for production from that of high value for biodiversity. In Brazil, a project is underway to zone areas for oil palm production in harmony with biodiversity conservation. Preliminary results include a zoning map for areas of suitable production for oil palm based on GIS data (Ramalho-Filho 2008).

Another method to prevent land cultivated for biofuels from encroaching on valuable natural ecosystems, is to direct new cropland to degraded lands. However, the only comprehensive source of information about land degradation is the Global Assessment of Human-induced Soil Degradation, which assesses degradation at a scale of 1:10 million (Wiegmann et al. 2008). A joint GEF/UNEP/

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[38] Coonan, C. (2008) China's new export: farmers. The Independent, December 29, 2008.

FAO/UNIDO project to better identify and assess the degraded areas suitable for biofuel production will utilise remote sensing techniques, as well as local knowledge to groundproof results on national and local scales (Wiegmann et al. 2008; Fritsche et al. 2008). Further research is needed on quantitative data regarding crop performance on degraded land in order to generate any realistic picture of the potential yields (if possible differentiating between food and non-food crops).

Comprehensive land use management guidelines that consider biofuels, agriculture, forestry, settlements/ infrastructure, mining and nature conservation are needed on regional, national and international levels for sustainable resource use.

Comprehensive land use management guidelines that consider biofuels, agriculture, forestry, settlements/infrastructure, mining and nature conservation are needed on regional, national and international levels for sustainable resource use. To avoid unintended consequences of development trends and to harmonise different interests in land use, a cross-sectoral approach will be necessary. To enhance consistency between sectoral policies and to balance the interests of different stakeholders, relevant actors should be involved in the preparation and implementation of national programmes for sustainable resource management. These programmes will need to take into account the impacts of national resource use to the domestic and, where relevant, also to the global environment (incl. induced global land use change and subsequent GHG emissions).

Exploitation of synergies between material and energetic use of biomass seems promising.

Research on the performance of advanced biofuels is necessary, considering the GHG and net energy balance, as well as primary material, land and water requirements.

7.3. Fostering more efficient use of biomass

Discovering and exploiting the synergies between material use and energetic use seems to hold the most promise for a sustainable biomass strategy. Cascading use may foster enhanced use of waste, which was originally derived from biomass, for energy provision. Policy approaches such as feed-in tariffs in developed countries and microfinance in developing countries have been effective in promoting more efficient resource use. Policy instruments that balance the use of residues and wastes with material and energetic use need to be further developed.

7.3.1. More resource efficient biofuels

The land requirements for advanced biofuels need to be assessed. If development is not restricted to waste and residues as feedstocks, land use will be necessary. The consequences for industries competing for the same feedstocks and the environmental consequences of second-generation feedstocks need to be studied further. Thus, when R&D investments on new generation biofuels occurs, accompanying research and monitoring on their environmental implications should be incorporated.

Residues and waste are candidates for more resource efficient biofuels in terms of land use. Relevant potentials have not yet been fully utilised for combining waste and residue disposal with energy generation (see section 6.4). These feedstocks can be used for stationary use or for transport, and the former seems more resource efficient under current technologies (see below). With regard to the liquid biofuel technologies under development, such as cellulosic biofuels derived from straw, corn stover or timber processing residues, research is needed to improve conversion efficiencies (including consideration of the potential costs and benefits of genetic engineering of feedstocks or processing micro-organisms). Accompanying research on the performance of advanced biofuels is necessary, considering the GHG and net energy balance, as well as primary material, land and water requirements when using various types of biomass, wastes and residues as feedstocks, in order to elucidate appropriate options for increasing resource efficiency.

7.3.2. Promoting power and heat applications

Particularly in developing countries, decentralised use of biofuels in stationary applications, such as power generators, can supply local communities with basic energy to enhance living and working conditions. The installation and maintenance may be organised by cooperatives, and supported by microfinancing mechanisms.

In some developed countries, stationary use of biofuels is fostered by feed-in tariffs for the electricity produced. This requires grid connections and available infrastructure. However, if the deployment of feed-in tariffs is not bound to sustainability standards for the biofuels utilised, stationary use may contribute to enhanced environmental pressure and trans-regional problem shifting. Therefore, when supporting the stationary use of biofuels under a wider sustainability perspective, the overall land use requirements of a country need to be considered in a comprehensive biomass action plan.

Box 7.1: Microfinance: a successful measure for promoting renewable energies

Microfinance has stimulated and facilitated the construction of 1,572 biogas plants in Nepal. The project, which started in 2005, increased access to microfinance for lower income purchasers to help overcome the high start-up costs of plant construction, especially in subsistence-based rural communities. Greenvillage Credit is part of UNEP's China Rural Energy Enterprises Development (CREED) project and explores a new approach to finance that entrusts loan capital to local, rural credit co-operatives, which serve as a platform for financial operations. It is intended to help local communities purchase better energy services with their own means. As of October 2005, more than 280 households have used this support to install sustainable energy devices, including biogas digesters, solar water heaters and improved cooking stoves/fireplaces (Wisions 2006). Many further examples of rural microcredit throughout Asia and Africa can be found in recent years. India's Renewable Energy Development Agency (IREDA) is a good example of a national public source of funds (REN21 2008).

The same applies to the energetic use of forestry products. Some European countries have ambitious targets for bioenergy use, such as Sweden, Finland and Austria. While these have led to increased use of biomass, more chips and pellets are being imported from other regions (Junginger et al. 2008). Research is required to further develop an adequate monitoring system for such trade (including the associated environmental impacts) and to provide countries with global reference values.

Overall land use requirements of a country need to be considered in a comprehensive biomass action plan.

7.3.3. Enhancing the use of waste and residues

In various countries, policies have been established to promote recycling and energy efficiency of waste management. Policy instruments will need to be further developed to balance potentially competing uses of residues for energetic and material use.

Some countries have designed specific instruments to foster market entry of renewable based energy technologies, including waste and residues. For instance, in Germany, the Renewable Energy Law[39] guarantees certain feed-in tariffs for power generation from manure and/or certain organic residues from agriculture which are digested to produce biogas, and for incineration of forest waste wood to make it competitive with fossil based power generation.

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[39] Act Revising the Legislation on Renewable Energy Sources and Amending Related Provisions. 21 October 2008, Germany. Published in the Federal Law Gazette I, No. 49.

Market-oriented measures, which assure a guaranteed price, can also be used. Green pricing, for instance, enables electricity customers to pay for renewable energies through direct payments on their monthly utility bills (Pons 2008). However, the criteria for what constitutes "green" is sometimes rather vaguely defined, and usually energy from various sources, including biomass from energy crops, is included. Therefore, when implementing such policies a comprehensive biomass strategy considering both material and energetic use of non-food biomass might help to minimise such conflicts.

7.4. Increasing energy and material productivity in transport, industry and households

The level of consumption needs to be significantly reduced for biofuels to be able to substitute relevant portions of fossil fuel use. For that to occur, resource efficiency in terms of services provided per unit of primary material, energy and land will need to be drastically increased.

Global resources do not allow patterns of current consumption to simply shift from fossil resources to biomass. Instead, the level of consumption needs to be significantly reduced for biofuels to be able to substitute relevant portions of fossil fuel use. For that to occur, resource efficiency in terms of services provided per unit of primary material, energy and land will need to be drastically increased.

Designing a policy framework by setting incentives for a more productive use of resources might be more effective and efficient in fostering sustainable resource use than regulating and fostering specific technologies.

Progress towards higher resource productivity is required on a worldwide scale. Affluent economies are challenged in particular, by their patterns of production and consumption, and developing countries must avoid adopting the unsustainable systems practiced in developed countries, which may lead to dead-ends. In light of currently high public and private investments into biofuels for comparably low returns in climate change mitigation, particularly for transport biofuels, and with respect to the high variation in net environmental benefits of current - and high uncertainties about future - biofuel technologies, governments and industry may consider emphasising other potentially more rewarding policies.

Various developed and developing countries and international organisations have formulated goals and targets for increased resource productivity (Factor X) in order to foster the decoupling of economic growth from resource consumption (Weizsäcker et al. 2009). Indicators have been developed to measure progress towards this end on the national, sectoral, company and product level (OECD 2008). Several countries have developed, or are in the process of developing, economy-wide and sectoral programmes to enhance energy and material efficiency in industry and households, such as the UK Resource Efficiency Network, Motiva (Finland), the Japan Forum on Eco-Efficiency (JFEE), and the German Material Efficiency Agency (DEMEA). Targets have been set, such as the EU Directive on energy end-use efficiency and energy services of 2006, which states that every member state must improve its energy efficiency by 1% on average every year. At its March 2007 summit, the EU has agreed to the target of saving 20% of its energy consumption compared to projections for 2020.

Designing a policy framework by setting incentives for a more productive use of resources might be more effective and efficient in fostering sustainable resource use than regulating and fostering specific technologies (as also suggested by IRGC 2008). Some developed countries and states have successfully established the use of economic instruments, such as transport fuel taxes, that have reduced overall fuel consumption and GHG emissions. The tax burden can be shifted from labour and capital to environmental related activities, particularly energy and environmental pollution. In Germany, environmental tax reform (ETR) was phased in from 1999 to 2003, with transport fuels generating about 10 billion euros in 2003 (roughly 56% of the total ETR revenues) with the major share of revenues employed in a tax shifting programme to reduce employers and employees' social security taxes (Speck 2008). Transport fuel consumption for diesel oil and motor spirit was reduced from just under 57 Mtoe in 2000 to approximately 50 Mtoe in 2005 (Eurostat 2007). Carbon emission trading also aims at an efficient allocation of financial resources. The industrial sectors involved have an interest to use and develop technologies with low GHG mitigation costs. Most biofuels of the first-generation would not have been the choice, if the transport sector had been part of the carbon trading system. Doornbosch and Steenblick (2007) have suggested that if national governments were to replace biofuel mandates with technology-neutral policies, such as a carbon tax, the development of efficient technologies would be better stimulated.

Some countries have set regulatory standards towards improving fuel economy. In the US, the Energy Independence and Security Act of 2007 demands that the fuel economy standards for cars

Box 7.2: Decoupling energy supply and harmful environmental impacts from economic development

Increasing energy and material productivity is one approach to meet the challenge faced, particularly by developing countries, of increased energy demand and growing environmental impacts. China, for instance, has set an ambitious target to enhance energy productivity by reducing energy intensity by 20% by 2010, from 2005 levels (Yang 2008). The enhanced use of resource efficient biofuel technologies, such as organic wastes and residues for power and heat generation in small-scale applications, may also contribute to a more efficient use of resources, improved energy supply and rural development.

and light trucks reach 35 miles per gallon (6.72 l/100km) by 2020, which requires a 40% increase in fuel economy (The White House 2007). The EU has set an emission limit of 130 g CO_2eq/km for new cars to be phased-in between 2012 and 2015, which is about an 18% reduction from current levels (EU 2009). Japan's Ministry of Economy, Trade and Industry (METI) is advancing their efforts to improve fuel efficiency by setting targets using the "top runner" approach. This method has been used in Japan since 1998 to promote the sale of energy efficient products in a wide range of industries. The original 2010 targets for passenger cars aimed at achieving a 23% improvement in fuel economy (compared to a 1995 baseline). New standards, to be implemented for 2015, will aim at a 20% improvement compared to 2004. Japanese vehicle manufacturers are currently reporting that more than 80% of their newly sold vehicles already comply with the original 2010 target levels (ACEA 2007).

In light of the current crisis and the climate change challenge, it is in the automotive industry's own interest to reduce GHG emissions and the resource requirements of their products. Some countries have already set fuel efficiency standards.

Judging from the global collapse in the automotive industry, the relevant companies have an interest to reduce the fuel consumption and GHG emissions of their products. Concerted action could drive the worldwide development rather quickly towards sustainability. A decisive step to this end could be a global agreement of automotive industries to reduce the GHG emissions and the resource requirements of their products by a significant amount within the years to come.

Altogether, various strategies and measures can be used to further develop policies which can effectively contribute to a more efficient and sustainable use of biomass and other resources.

Section 8: Needs for research and development

The following key research needs have been identified in the preparation of this report:

Further exploring potentials and implications of biomass use

- Improve estimates on global land use change due to changing consumption patterns of food
- Measure nitrogen balances of agriculture particularly with regard to N_2O emissions (incl. off-site)
- Explore production routes of low input agriculture/forestry feedstocks and efficient conversion technologies for material and energy use
- Compare bioenergy pathways in different environments/locations (e.g. stationary vs. mobile use)
- Study the consequences of growing energetic use of forestry products
- Analyse the environmental implications (especially GHG emissions and land requirements) and economic viability of 2nd and 3rd generation biofuels
- Assess the overall implications of using sustainability criteria for biofuels in particular in certification schemes

Making better use of biomass

- Develop cascading use of biomass
  - Determine the full potential of bio-based materials with regard to systems-wide sustainable resource use, considering the whole range of biomass use (food, fibre, fuels).
  - Examine the potential of cascading systems to reduce resource requirements (land, primary materials and energy) and environmental impacts
  - Develop decision support for policy and industry in order to avoid misleading incentives and make better use of combined material and energy use
- Advance use of residues and waste
  - Clarify the role of residues in soil protection, maintaining soil carbon content, and nutrient cycling to determine what fraction can be removed
  - Clarify nutrient recycling for waste incineration
- Analyse N_2O emissions from biogas producing facilities

Improve global land use

- Further develop and implement ecologically friendly measures to increase yields, especially in developing countries such as Sub-Saharan Africa
- Identify the realistic production potential and consequences of using degraded land
  - Determine extent and potential of land, adequate crops and cultivation systems
  - Develop land assessment to assess whether land conversion makes more sense than allowing natural regeneration to occur
- Develop integrated land use planning comprising agriculture, forestry, settlements/infrastructure/mining and nature conservation, considering actual and potential future resource use
- Further develop indicators and reference values to inform countries of their domestic and global resource use (in particular global land use associated with domestic consumption)

Compare and develop potentially more resource efficient alternatives

- Explore and develop the various options to reduce fuel and resource consumption of transport
- Compare energy services of solar vs. biomass (environmental, social, and economic performance) in different world regions to provide guidance for decision makers
- Further develop solar technologies such as PV to become more economical, while considering material resource intensity, implications of hazardous compounds, reducing production emissions, and enhancing the options for recycling
- Develop approaches to reduce over-consumptive diets of animal-based products
- Determine actual post-harvest losses of biomass and wastage of food and ways to minimise those flows

Improve methodologies and safeguards

- Further develop biofuel certification, and accompanying mechanisms to better
  - consider indirect land use change, GHG effects and other impacts, such as eutrophication, more comprehensively; in particular, to
  - combine product and production-chain specific criteria with findings on the macro level (e.g. projections of overall biomass and related land use of a net importing country)

- Harmonise rules on how to carry out LCAs on biofuels
  - Set reasonable guidelines and assumptions for methodological issues
  - Determine how to deal with the associated uncertainty of key parameters (e.g. allocation rules of impacts on co-products, N_2O emission rates, land use, carbon stocks, technology progress, etc.)
  - Include water-consumption and pollution issues

- Develop technologies and political mechanisms to reduce the demand of energy, material, and land intensive activities

Section 9: **References and further reading**

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Section 10: Appendix

Box A.1: Research Initiatives and Support Mechanisms for Decision Makers

The research initiatives for decision-making in sustainable bioenergy development address specific sectoral related research, as well as collaborating integrated fields of research and assistance. Presently, a majority of these initiatives are led by working groups and task force schemes. Some significant areas of research include issues related to methodology assessment for full life-cycle analysis, sustainable trade and bioenergy market development, technical guidance on production technology, and research and tools for sustainable commercialisation. Through deliverables such as tools, reports, evaluations and technical assistance, these initiatives are serving to guide decision makers and give them tools to support sustainable bioenergy practices. Some examples include:

IEA/OECD, Task 38: Greenhouse Gas Balances of Biomass and Bioenergy Systems: Task 38 researches and analyses existing information on full fuel cycles of bioenergy systems in an attempt to estimate GHG balances for robust quantification. Deliverables of this task force include simplified software tools for projecting emissions reductions of sequestration and position papers for decision makers.

UN-Energy: UN-Energy is an UN inter-agency mechanism that promotes coherence in the UN system's multi-disciplinary response to the World Summit on Sustainable Development (WSSD). A recent deliverable of UN-Energy is a policy response report entitled "Sustainable Bioenergy: A Framework for Decision Makers". Currently a decision support tool is under development.

FAO, Bioenergy and Food Security Project (BEFS): The BEFS provides policy and technical assistance in four countries to implement bioenergy programs that use a modelling framework to assess future scenarios and predict impacts on household food security.

UNEP, Bioenergy Planning Tools: In an effort to inform policy on resource efficiency and conservation, and to provide rapid response support to governments, UNEP is developing guidance materials and bioenergy planning tools. For example, UNEP's Resource Panel is preparing a report on different aspects of resource efficiency related to biofuels, both on the macro and the project level. An initiative was started to facilitate the development of mechanisms and mapping tools to integrate conservation value areas into bioenergy planning.

Competence Platform on Energy Crop and Agro Forestry Systems for Arid and Semi-arid Ecosystems - Africa (COMPETE): Established within the EU International Scientific Cooperation Activities, COMPETE serves as a forum to facilitate policy dialogue and information exchange concerning the development of sustainable bioenergy in Africa. A key focus of the organisation is developing policy mechanisms that enhance local value-added community development.

Source: compilation by UNEP-DTIE

Box A.2: International Platforms for Dialogue

There are a host of platforms and partnerships in which global dialogue for sustainable bioenergy practices and information exchange have been formed. Many of these initiatives are cross-sectoral and integrate multi-stakeholder participation into the bioenergy dialogue. Of these UNIDO, UNEP, UNCTAD and FAO support high level policy dialogue through working groups, partnerships, capacity building and information sharing, to assist in sustainable application of bioenergy policies and production. Some deliverables of these collaborations have been highlighted below:

Global Bioenergy Partnership (GBEP): Implemented as an initiative taken by the G8+5 countries in the 2005 Gleneagles Plan of Action, GBEP aims to support three pillars of action through partnerships with public, private, and civil society stakeholders. These focal points of activities include energy security, food security, and sustainable development.

Roundtable on Sustainable Biofuels (RSB): The RSB is a multi-stakeholder initiative bringing together the private sector, NGOs, governments, and experts in an effort to create principles and policy recommendations for the sustainable use and production of biofuels. The RSB has established a Bioenergy Wiki website for information exchange and knowledge sharing, released its “Draft Global Principles for Sustainable Biofuels Production”, and has structured ‘Expert Advisory Groups’ for specific issues in the bioenergy debate.

FAO, International Bioenergy Platform: This platform was launched in 2006 to assist in the development of an international scheme for assurances and certification principles, methodologies, criteria and verifiable indictors for sustainable bioenergy production. The two pillars identified by the platform are (1) information collection and (2) mobilisation and implementation at a country level.

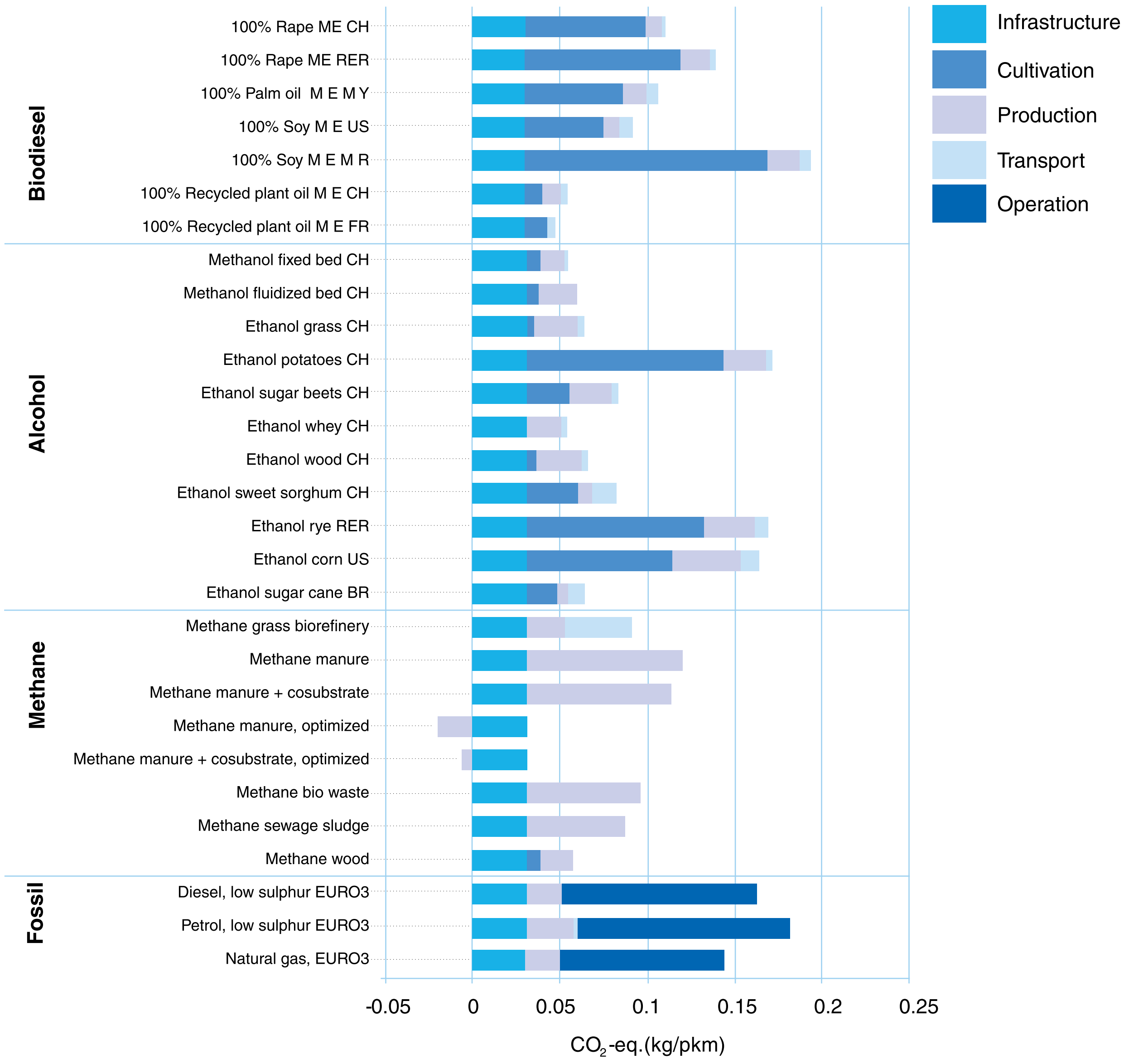
UNIDO Bioenergy Interregional Network: This network assists in the cooperation among regions in promoting bioenergy related research, mobilising investments, and technology transfer. It aims to achieve this and the creation of sustainable criteria by developing support tools and by being a platform for dialogue among stakeholders to develop sustainability aspects into bioenergy value chains.

UNEP – Rural Energy Enterprise Development

This UNEP initiative seeks to develop new sustainable energy enterprises that use clean, efficient, and renewable energy technologies to meet the energy needs of poor households in developing countries. Phase two of the African Rural Energy Enterprise Development project will have a strong bioenergy component. In addition, UNEP has launched a network of Centres of Excellence that support successful business models for farmers to participate in the production and use of modern forms of energy and overcome barriers for financing.

Source: compilation by UNEP-DTIE

Figure A.1: Comparison of greenhouse gas emissions of biofuels for transport with fossil fuels (gasoline and diesel, EURO 3 norm) differentiated by phases.



Source: Zah et al. (2007).

Table A.1: Overview of current and projected performance data for the main conversion routes of biomass to power and heat and summery of technology status and deployment

Conversion option	Typical capacity	Net efficiency (LHV basis)	Investment cost ranges (Euro/kW)	Status and deployment
Biogas production via anaerobic digestion	Up to several MWe	10-15% electrical (assuming on-site production of electricity)		Well established technology. Widely applied for homogeneous wet organic waste streams and waste water. To a lesser extent used for heterogeneous wet wastes such organic domestic wastes.
Landfill gas production	Generally several hundred kWe	As above.		Very attractive GHG mitigation option. Widely applied and, in general, part of waste treatment policies of many countries.
Combustion for heat	Residential: 5-50 kWth Industrial: 1-5 MWth	Low for classic fireplaces, up to 70-90% for modern furnaces.	~100/kWth for logwood stoves, 300-800/kWth for automatic furnaces, 300-700/kWth for larger furnaces	Classic firewood use still widely deployed, but not growing. Replacement by modern heating systems (i.e., automated, flue gas cleaning, pellet firing) in e.g., Austria, Sweden, Germany ongoing for years.
Combined heat and power	0,1-1 MWe 1-20 MWe	60-90% (overall) 80-100% (overall)	3500 (Stirling) 2700 (ORC) 2500-3000 (Steam turbine)	Stirling engines, steam screw type engines, steam engines, and organic ranking cycle (ORC) processes are in demonstration for small-scale applications between 10 kW and 1 MWe. Steam turbine based systems 1-10 MWe are widely deployed throughout the world.
Combustion for Power generation	20->100 MWe	20-40% (electrical)	2.500-1600	Well established technology, especially deployed in Scandinavia and North America; various advanced concepts using fluid bed technology giving high efficiency, low costs and high flexibility. Commercially deployed waste to energy (incineration) has higher capital costs and lower (average) efficiency.
Co-combustion of biomass with coal	Typically 5-100 MWe at existing coal-fired stations. Higher for new multifuel power plants.	30-40% (electrical)	100-1000 + costs of existing power station (depending on biomass fuel + co-firing configuration)	Widely deployed in various countries, now mainly using direct combustion in combination with biomass fuels that are relatively clean. Biomass that is more contaminated and/or difficult to grind can be indirectly co-fired, e.g., using gasification processes. Interest in larger biomass co-firing shares and utilisation of more advanced options is increasing.
Gasification for heat production	Typically hundreds kWth	80-90% (overall)	Several hundred/ kWth, depending on capacity	Commercially available and deployed; but total contribution to energy production to date Limited.
Gasification/ CHP using gas engines	0.1-1 MWe	15-30% (electrical) 60-80% (overall)	1.000-3.000 (depends on configuration)	Various systems on the market. Deployment limited due to relatively high costs, critcal operational demands, and fuel quality.
Gasification using combined cycles for electricity (BIG/CC)	30-200 MWe	40-50% (or higher; electrical)	5.000 – 3.500 (demos) 2.000 – 1.000 (longer) term, larger scale)	Demonstration phase at 5-10 MWe range obtained. Rapid development in the nineties has stalled in recent years.First generation concepts prove capital intensive.
Pyrolysis for production of bio-oil	10 tonnes/hr in the shorter term up to 100 tonnes/hr in the longer term.	60-70% bio-oil/feedstock and 85% for oil +char.	Scale and biomass supply dependent; Approx 700/kWth input for a 10 MWth input unit	Commercial technology available. Bio-oil is used for power production in gas turbines, gas engines, for chemicals and precoursors, direct production of transport fuels, as well as for transporting energy over longer distances.

*Note: Due to the variability of technological designs and conditions assumed, all costs are indicative

Source: IEA Bioenergy 2007 (adapted from van Loo and Koppejan 2002; Knoef 2005; USDOE 1998; Dornburg and Faaij 2001)

About the UNEP Division of Technology, Industry and Economics

The UNEP Division of Technology, Industry and Economics (DTIE) helps governments, local authorities and decision-makers in business and industry to develop and implement policies and practices focusing on sustainable development. The Division works to promote:

- sustainable consumption and production,
- the efficient use of renewable energy,
- adequate management of chemicals,
- the integration of environmental costs in development policies.

The Office of the Director, located in Paris, coordinates activities through:

- **The International Environmental Technology Centre -** IETC (Osaka, Shiga), which implements integrated waste, water and disaster management programmes, focusing in particular on Asia.
- **Sustainable Consumption and Production** (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.
- **Chemicals** (Geneva), which catalyzes global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.
- **Energy** (Paris), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.
- **OzonAction** (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.
- **Economics and Trade** (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies.

UNEP DTIE activities focus on raising awareness, improving the transfer of knowledge and information, fostering technological cooperation and partnerships, and implementing international conventions and agreements.

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