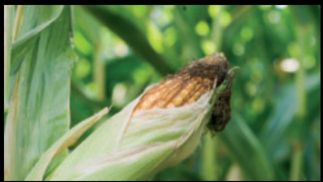
UNEP

International Panel
for Sustainable
Resource Management

Towards sustainable production and use of resources:



ASSESSING BIOFUELS

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The following is an excerpt of the report

Towards Sustainable Production and Use of Resources:

ASSESSING BIOFUELS

produced by the
International Panel for Sustainable Resource Management.

This document highlights key findings from the report, and should be read in conjunction with the full report. References to research and reviews on which this report is based are listed in the full report.

The full report can be downloaded at: **www.unep.fr**

or can be ordered on a CD Rom from:

United Nations Environment Programme
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15 rue de Milan, 75441 Paris CEDEX 09, France

preface

Biofuels have attracted the 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)

Objective and scope

about the International Panel for Sustainable Resource Management & objective and scope of the report.

Contribute to a better understanding of how to decouple economic growth from environmental degradation.

The International Panel for Sustainable Resource Management

The Resource Panel was established to provide independent, coherent and authoritative scientific assessments of policy relevance on the sustainable use of natural resources and in particular their environmental impacts over the full life cycle. It aims to contribute to a better understanding of how to decouple economic growth from environmental degradation.

The report Towards Sustainable Production and Use of Resources: Assessing Biofuels is part of a series of reports on a variety of topics.

Provide an overview of key problems and perspectives towards sustainable production and use of biomass for energy purposes.

Objective and scope of the report

This report 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.

It provides an overview of the key problems and perspectives towards sustainable production and use of biomass for energy purposes. In particular, the report examines options for more efficient and sustainable production and use of biomass. In the overall context of enhancing resource productivity, it addresses «modern biomass use» for energetic purposes, such as biomass used for (co-)generation of heat and power and liquid biofuels for transport, and relates it 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.

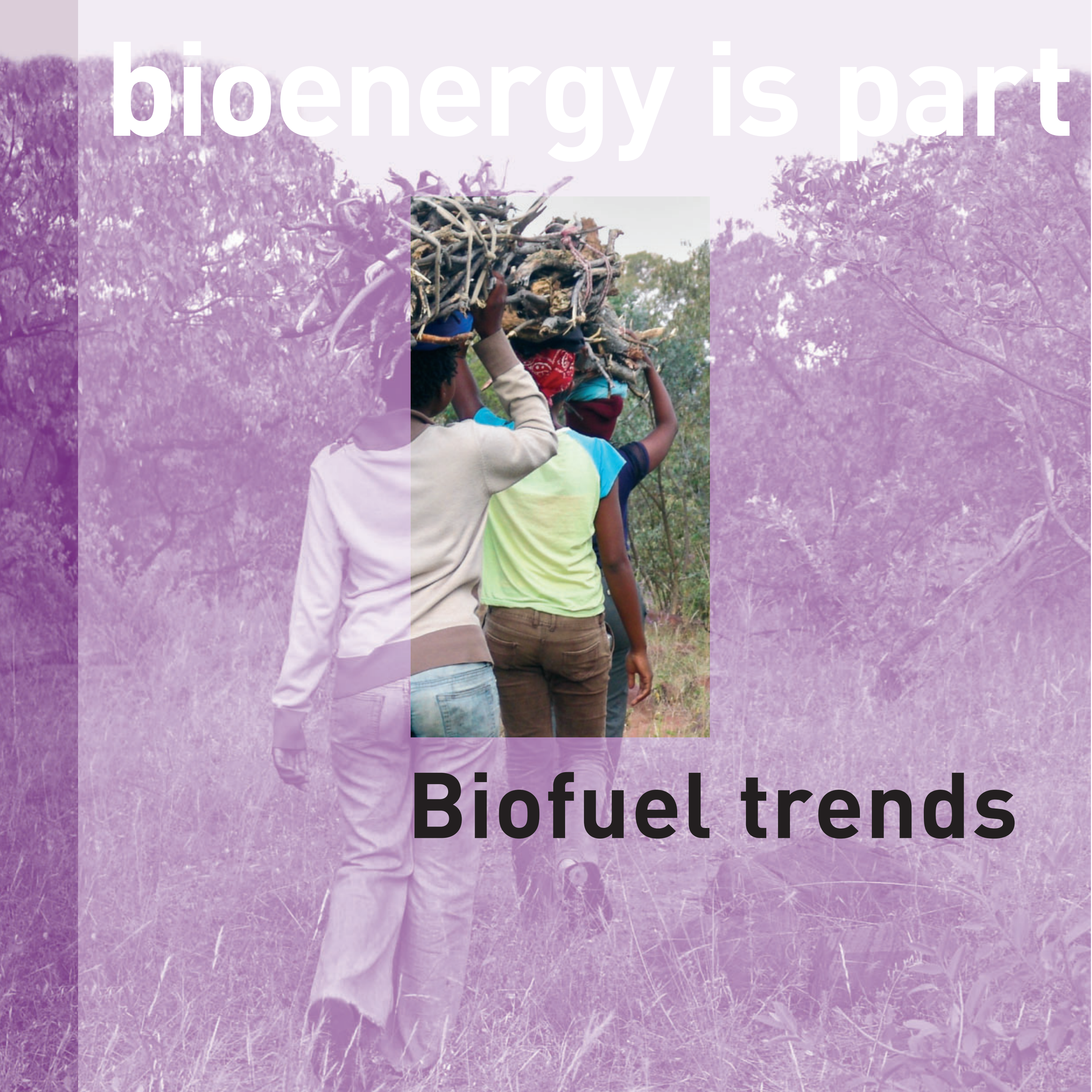
This report mainly covers so-called first generation biofuels while considering also further lines of development. This is due to state-of-the-art and data availability until the end of 2008. Potential benefits and impacts of second and third generation biofuels – preferably referred to as 'advanced biofuels' – are partially included, and might be subject to a specific report at a later stage.

This report focuses on the global situation, recognising regional differences.

Finally, the report marks uncertainties and highlights needs for research and development.

The key question that occurred is whether significant expansion of biofuel production is 'too much of a good thing'.

bioenergy is part



Biofuel trends

Bioenergy, **so far largely in the form of traditional use of biomass,** is part of the energy mix.

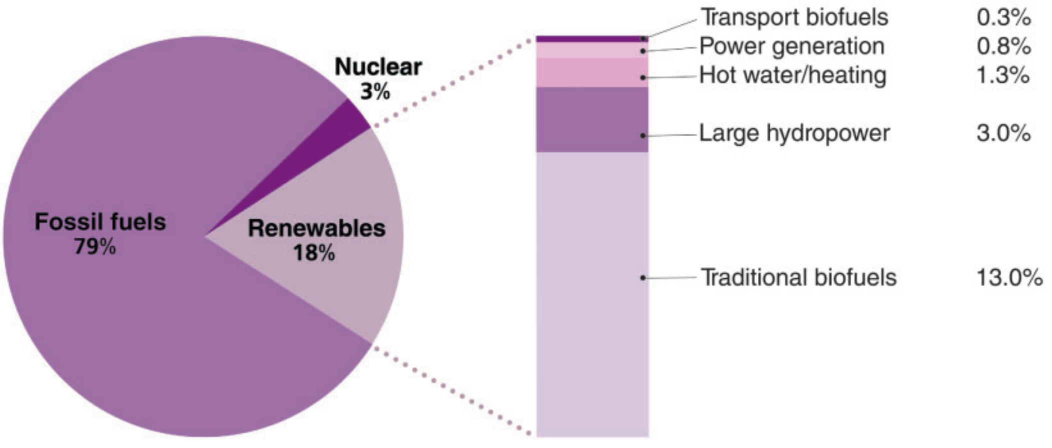
Traditional biomass use currently provides 13% of global final energy demand.

Traditional biomass use currently provides 13% of global final energy demand.
In developing countries, over 500 million households still use traditional biomass for cooking and heating. However, these trends are changing and 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.

Figure 1: Renewable energy share of global final energy consumption (GFEC) in 2006



Source: REN21 (2008)

bioenergy is part of the energy mix

Liquid biofuels provided a total share of 1.8% of the world's transport fuel by energy value in 2007.

World ethanol production for transport fuel tripled from 17 billion to more than 52 billion litres between 2000 and 2007, while biodiesel expanded eleven-fold from less than 1 billion to almost 11 billion litres. This resulted in liquid biofuels providing a total share of 1.8% of the world's transport fuel by energy value in 2007. A recent estimate for 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 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.

Figure 2: Global bioethanol and biodiesel production 1975 to 2007

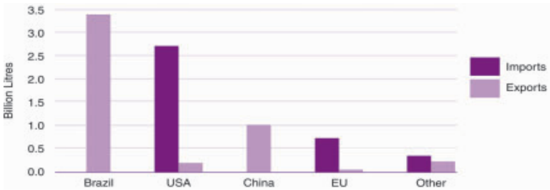
Source: REN21 (2008)

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).

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.

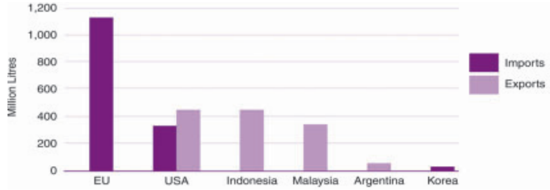
Investment into biofuels production capacity probably exceeded $4 billion worldwide in 2007 and seems to be growing rapidly. Industry with government support also invests heavily in the development of advanced biofuels.

Figure 3: **International trade in ethanol, 2006**



Source: Data complied from OECD (2008), according to F.O. Licht's (2008)

Figure 4: **International trade in biodiesel, 2007**



Source: Data complied from OECD (2008), according to LMC (2007)

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.

International trade in ethanol and biodiesel has been small so far but is expected to grow.

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.

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.

putting biofuels

Global challenges

into perspective

Long term sustainability of the bioenergy sector can only be achieved with sound policies and planning that take into consideration a range of global trends, including **population growth, yield improvements, changing diet patterns and climate change.**

A growing population

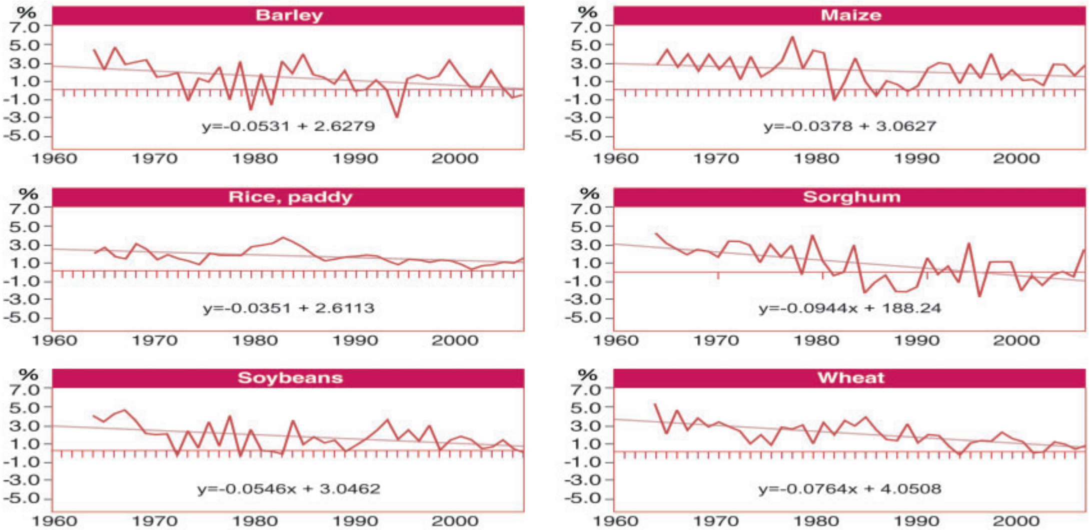
The global population is expected to grow by 36% between 2000 and 2030, from 6.1 billion in 2000 to approximately 8.3 billion (medium projection of UN/FAO). Developing countries will contribute the most to this increase with their total population increasing from 4.7 to 6.9 billion over the same period (plus 45%).

Development of agricultural yields

Data from the FAO show that relative yield increases in the last decades have in general weakened. Data from 1961 to 2005 show reduced average annual percent yield increases of six field crops.

For the world average, cereal yields are predicted to grow about as fast as overall population.

Figure 5: **Change in growth rate of global crop yields (in %) – 5 year moving averages**



Note: t-statistic for regressions: Barley: -2.61**; Rice, paddy: -3.70***; Sorghum: -4.32***; Soybeans: -3.06***; Wheat: -5.82*** ***and ** indicate significance at the 1 and 5 % two-side confidence interval respectively).
Source: based on FAOSTAT online data (2008)

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.

Recent findings show that climate change has already reduced average crop yields.

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; and more food could be produced on existing cropland. In the future, the trends might become less favourable, as average crop yields may

Any further land requirements for fuel crops will be added on top of this demand.

compensate for population growth but not for an increasing demand of animal based food. Between 2000 and 2030 it is expected that average crop yields increase at the same rate as population growth.

At the same time, however, food demand is changing towards a higher share of animal based diets, particularly in developing countries where meat consumption was low.

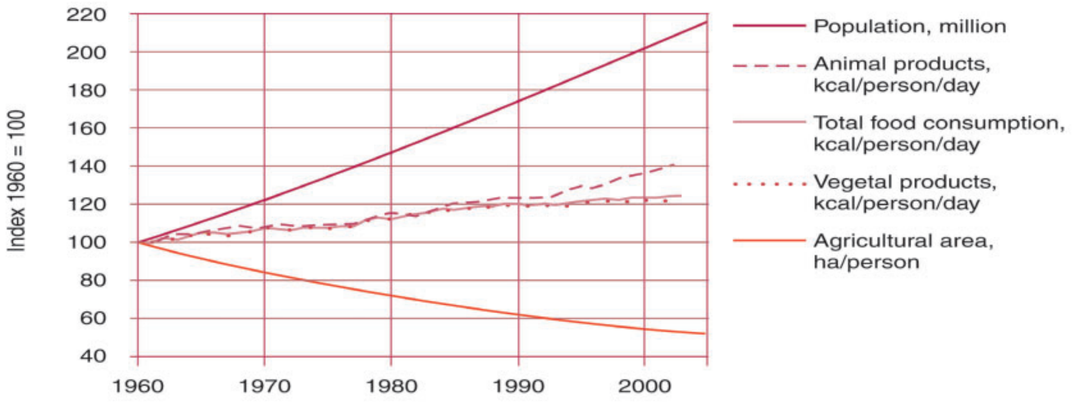
The FAO expects the meat consumption of the world population to increase by 22% per capita from 2000 to 2030, the milk & dairy consumption by 11% and that of vegetable oils by 45%. Commodities with lower land requirements like cereals, roots and tubers, and pulses will increase at lower rates per capita.

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 , an estimated additional requirement of 144 to 334 Mha of global cropland for food in 2020 can be derived.

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

Figure 6: **Development of global population, agriculture land and consumption per person in the past (1960 - 2005)**



Source: UN population statistics online; FAOSTAT online

Global challenges

not all biofuels

Life-cycle

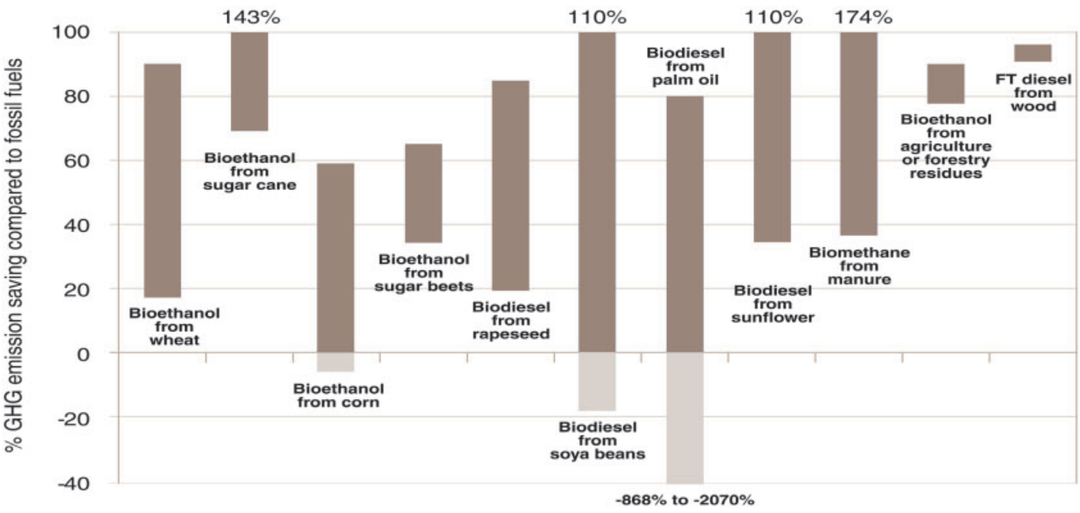
are equal

Biofuels may make a difference in terms of achieving the different policy objectives pursued. However, not all biofuels perform equally well in terms of their impact on climate, energy security, and on ecosystems. **Environmental and social impacts need to be assessed throughout the entire life-cycle.**

The green house gas balances of biofuels

Life-cycle-assessments (LCA) of biofuels show a wide range of net greenhouse gas balances compared to fossil fuels, depending on the feedstock and conversion technology, but also on other factors, including methodological assumptions. 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

Figure 7: **Greenhouse gas savings of biofuels compared to fossil fuels**



Source: 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

not all biofuels are equal

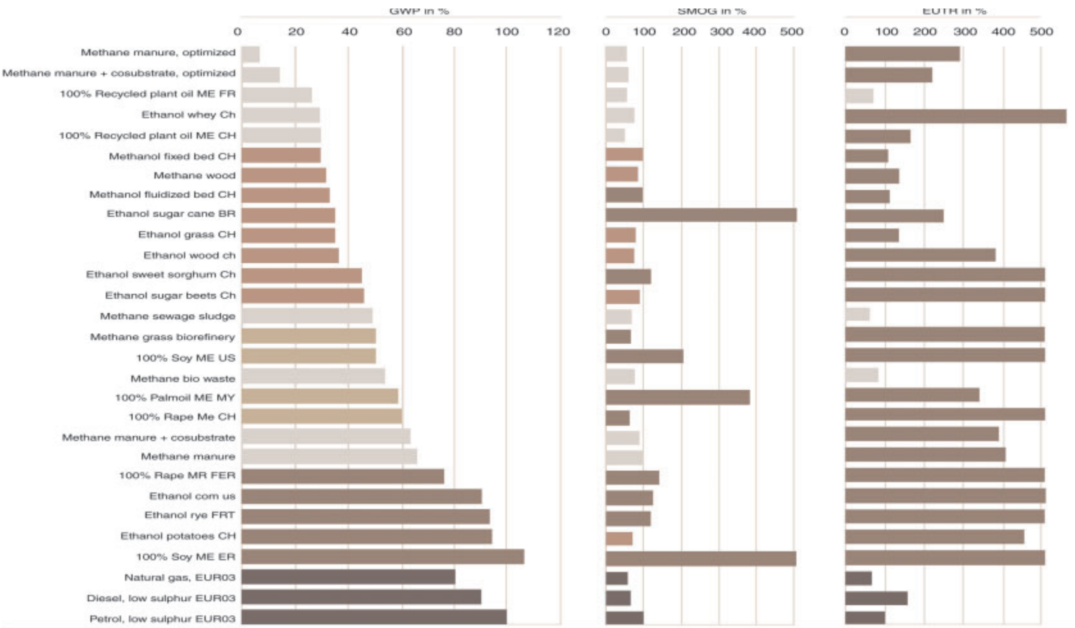
LCAs should account for GHG emissions from land use change, water and biodiversity.

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 of biofuels, such as on water and biodiversity, are hardly considered in existing LCAs. Also, impacts such as eutrophication and acidification that are indeed relevant and

Figure 8: **Life-cycle impact assessment of biofuels compared to fossil fuels for different environment 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 diagramms:
- Better than reference.
- Worse than reference.

Source: Zah et al. (2007)

have already contributed to significant worsening of environmental quality in some regions, 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.

LCAs should account for eutrophication and acidification.

Methodological constraints influencing results

LCA provide useful guidance to compare different technologies and production methods. However, when interpreting results, attention should be paid to varying assumptions and methodological constraints which result in a wide variation in LCA results.

There is uncertainty about N_2O emissions.

In addition, 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.

Depreciation periods influence results.

Another component that needs to be considered when comparing LCA results is the way in which 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.

Water

■ Water quality
■ Water consumption

Impact assessments on project level and at regional scale are needed.

Crop types, production methods and conversion technologies need to be matched with local conditions.

Water quality

There is a link between environmental impacts estimated by life-cycle impact assessments on a project level 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 (shortage of oxygen). Changing agricultural practices with the relevant feedstock crop may mitigate some of the pressures, but will most probably not be sufficient to improve regional environmental conditions, such as water quality.

Water consumption

Agriculture currently uses some 70% of fresh water globally, and biofuel development would add to this. Water consumption varies with crop types used as feedstocks as well as production methods and conversion technologies. Feedstock production for biofuels in water scarce regions requires irrigation, which may lead to competition with food production as well as pressure on water resources beyond the restoration capacity.

Extreme weather events (inundation, droughts) due to climate change might increase uncertainty in terms of available water resources.

impacts from

Land use

As future global biofuel demand is expected to increase, so is the **demand on land.**

Actual and planned land use for crop production

Global land use for the production of biofuel crops – mainly sourced from food crops – is growing. In 2008, biofuel crop production covered about 2.3% or about 36 Mha of global cropland, as compared to 26.6 Mha or 1.7% of global cropland in 2007, and 13.8 Mha or about 0.9% of global cropland in 2004. With growing demand for biofuels, the extension of cropland for biofuel production is continuing, in particular in tropical countries where natural conditions favour high yields. This development is driven by volume targets rather than by land use planning. 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.

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

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 from land use change

Land conversion for biofuel crops can lead to negative environmental impacts including implications such as **reduced biodiversity and increased GHG emissions.**

Clearing the natural vegetation mobilises the stocked carbon and may lead to a carbon debt.

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.

Increased biofuel production is expected to have large impacts on biological diversity.

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 change»).

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.

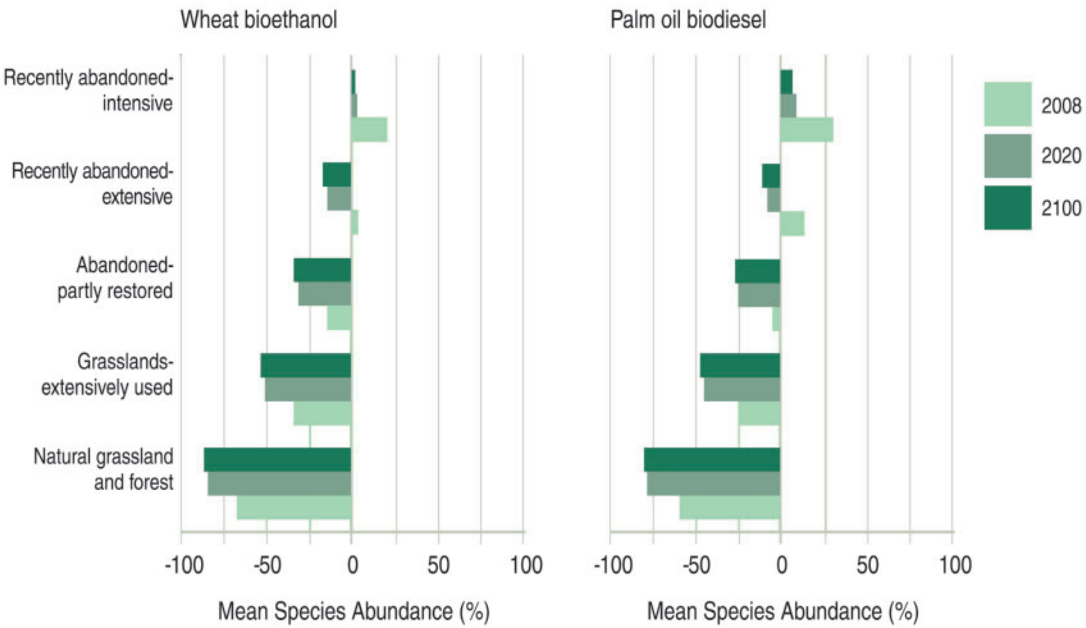
Increased biofuel production is expected to have large impacts on biological diversity in the coming decades, mostly as a result of habitat loss, increased invasive species and nutrient pollution. Habitat loss will mainly result from cropland expansion. Species and genotypes of grasses suggested as future 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.

Use of abandoned or degraded land can help reduce pressure on land.

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.

Figure 9: 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)

reducing

Options for higher resource efficiency

There are avenues available to create more efficient and sustainable production of biomass, and thereby **reduce environmental pressures.**

Options range from measures to improve the efficiency of production of biomass, such as increasing yields and optimising agricultural production and restoring formerly degraded land, to more efficient use of biomass, including use of waste and production residues, cascading use of biomass, stationary use of bioenergy, to considering different pathways, for example, considering mineral based solar energy systems.

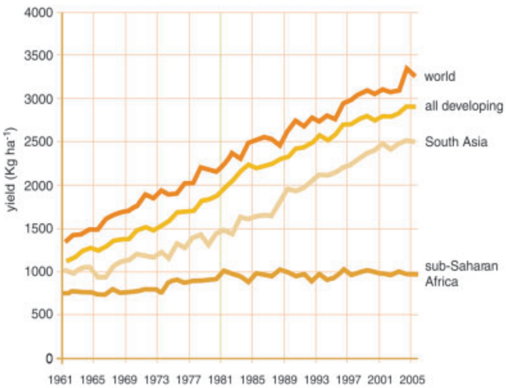
Improving the production of biomass

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.

Crop choices and cultivation methods need to be adjusted to local conditions.

Figure 10: **Global trends in cereal yields by region (1961 - 2005)**



Source: Hazel & Wood (2008) (adapted from FAOSTAT 2006)

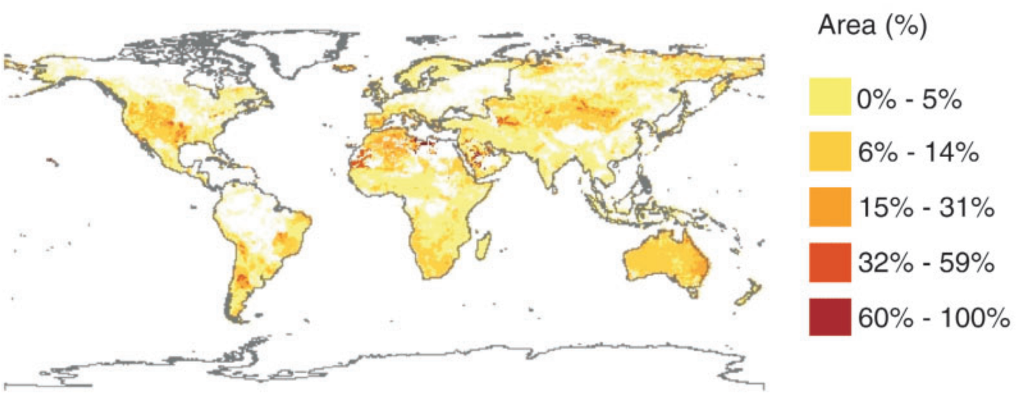
Research is needed to clarify realistic production potentials.

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. For instance, some of the areas currently classified as "marginal" may also in fact harbor high levels of biodiversity.

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

Figure 11: Worldwide potential of abandoned land



Source: Campbell et al. (2008)

Using biomass more efficiently

Use of waste and production residues

The proper balance of residues that should remain on the field or in the forest, and the amount that can be removed for energy needs to be determined.

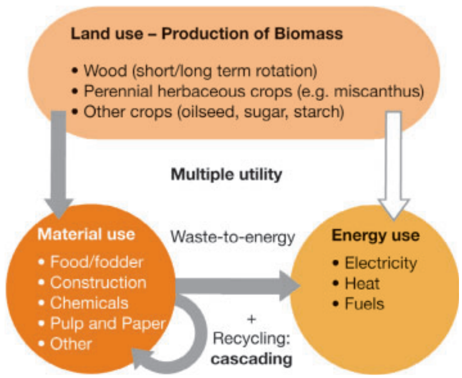
Energy recovery from waste and residues can save significant GHG emissions without requiring additional land. Specifically, municipal organic waste and residues from agriculture (both crop production and animal husbandry) and forestry provide a significant energy potential which is still largely unused. 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. 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

The potential for cascading use needs to be determined with regards to biomass uses and resource requirements.

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, concurrently maximizing GHG mitigation potential. 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).

Figure 12: Cascading use of biomass



Source: after Dornburg (2004)

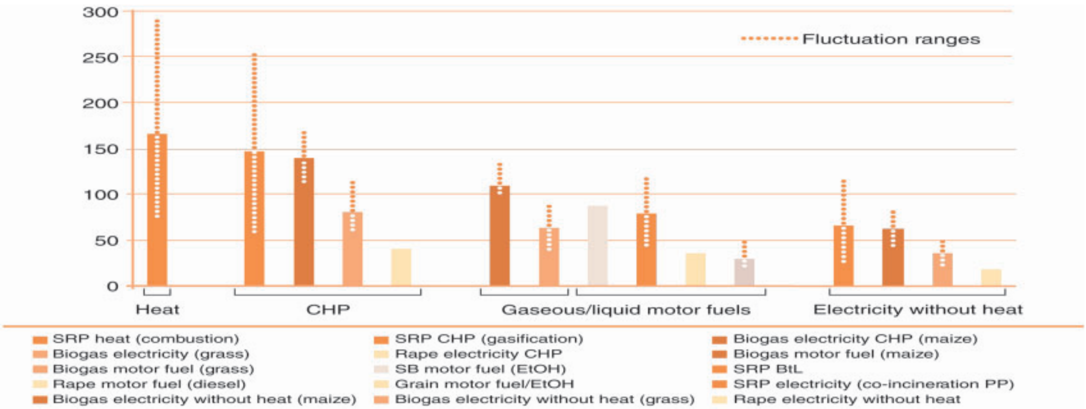
Using biomass for power and heat

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.

The substitution of traditional biomass use for heating and cooking may help overcome energy poverty and improve health conditions.

Figure 13: **Overview of current energy yields (net) of renewable raw materials for different usage paths in GJ/ha**



*Notes: Using Miscathus (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 efficiences are included; in the case of motor fuels only the production losses, but not the 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
Sources: SRU (2007) (adapted from LfU 2004: Arnold et al. 2006; DENA 2006; FNR 2005, 2005b, 2006; Keymer & Reinhold 2006; Schindler & Weindorf 2006)

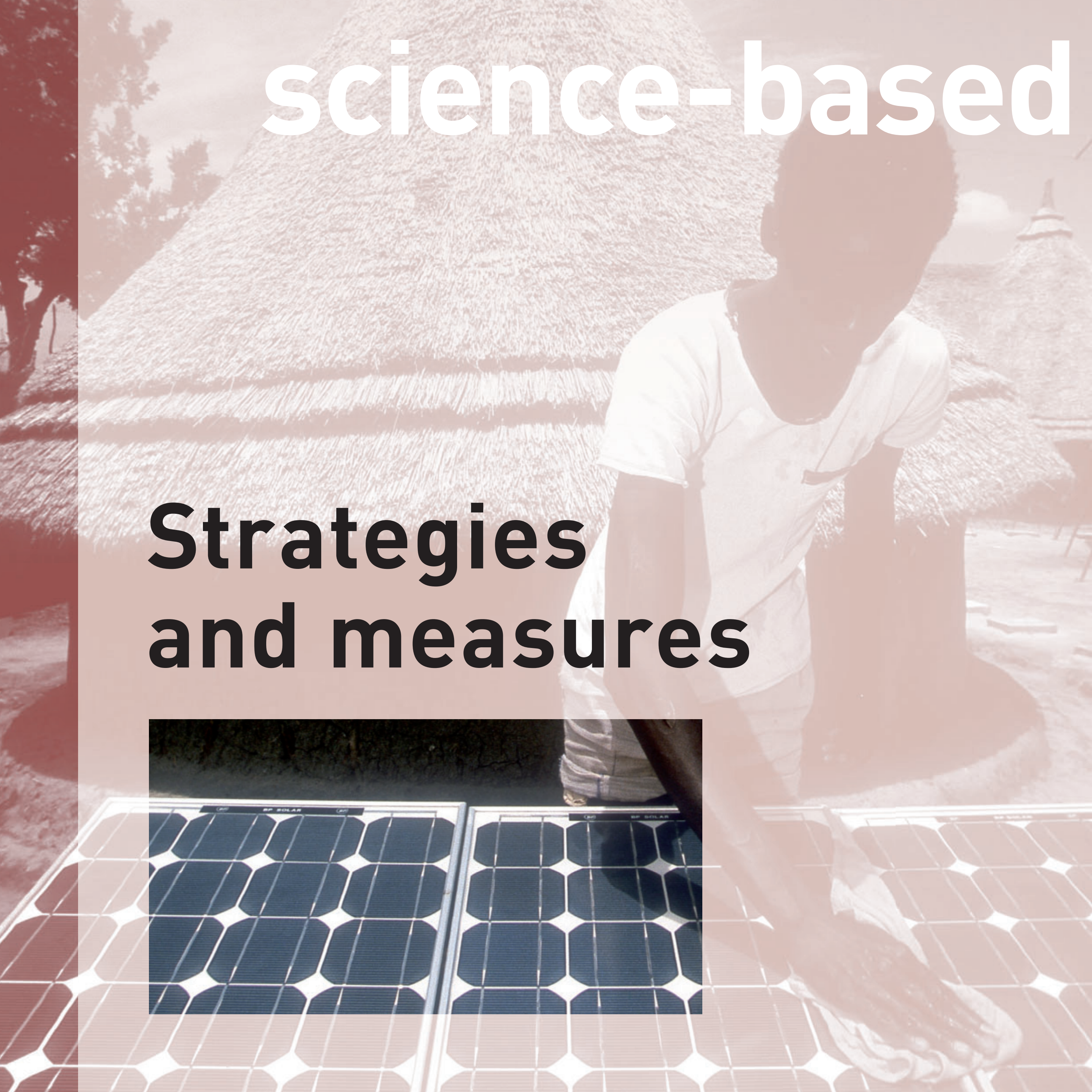
Considering different energy supply systems

Mineral based solar energy systems

Mineral based solar energy systems transform solar radiation more efficiently into useable energy.

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. Furthermore 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

policies

Sustainable biofuel production can occur when **strategies** are implemented to increase resource productivity. Certain **measures** can reduce environmental pressures on natural resources and provide social benefits.

Mandates and targets have come under scrutiny as being insufficiently supported by science.

Policy instruments are needed which foster sustainable land use patterns and adjust demand to levels which can be supplied sustainably.

Mandates, Targets and Standards

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 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. 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 sustainability standards for sustainable bioenergy production. These standards and related certification schemes rely on project based life-cycle assessments 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 and acidification 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.

- Further develop production standards and product certification of biofuels to consider all relevant environmental and social impacts
- For a sufficient assessment of biofuels consider information on both,
  - specific types of products and production conditions, and

- overall consumption and land use for biomass

- Reconsider current policy mandates, targets, quota (limit demand to levels which can sustainably be supplied)
- Develop national and regional resource management programmes
  - incl. climate and biodiversity protection, food and energy security
  - consider land use for domestic consumption (limit burden shifting)
- Use economic instruments to increase resource productivity (e.g. reform subsidies including those of fossil fuels)

Fostering sustainable land use for biomass production

Comprehensive land use management guidelines are needed on the regional, national and international levels.

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.

Low input cultivation of perennials is being explored. While this may help to reduce pressure on land, water and required inputs, concerns related to biodiversity and land use – if development takes place on arable or high conservation value land - remain.

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).

- Mobilize agricultural potentials in

regions that have lagged – increase yields in an environmentally & socially benign manner

- Limit expansion of cropland and direct new development to degraded land, considering potential environmental and social impacts
- Explore low input cultivation of perennials to limit eutrophication

Fostering more efficient use of biomass

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.

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.

- Promote energy from residues/waste rather than energy crops
- Foster cascading use of biomass
- Promote use of bioenergy for stationary application rather than for transport

Consumption levels need to be reduced significantly for biofuels to be able to substitute for relevant portions of fossil fuel use.

Incentives for more productive use of resources might be more effective and efficient than regulating and fostering specific technologies.

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, and to move towards providing mobility services.

- Limit overall biomass & energy demand, particularly increase fuel efficiency of vehicles and foster modal shifts

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.

abbreviations, acronyms and units

Abbreviations and acronyms

BtL	biomass to liquid
CHP	combined heat and power
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FT	Fisher-Tropsch
GFEC	global final energy consumption
GHG	greenhouse gas
GWP	global warming potential
IFEU	Institute for Energy and Environmental Research
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle assessment
OECD	Organisation for Economic Co-operation and Development
RFA	Renewable Fuels Agency
RSB	Roundtable on Sustainable Biofuels
SCOPE	Scientific Committee on Problems of the Environment
UNEP	United Nations Environment Programme

Units

a	year
CO_2eq	carbon dioxide equivalents
EJ	exajoule (1018 joules)
Gt	gigatonne (109 tonnes)
GW	gigawatt (109 watts)
ha	hectare
Mha	million hectares
p.a.	per annum
t	tonne

Chemical abbreviations

CO_2	carbon dioxide
EtOH	ethanol
N_2O	nitrous oxide

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THIS REPORT was produced by the Working Group on biofuels of the International Panel for Sustainable Resource Managemet. It 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. The focus is on so-called first generation biofuels while considering further lines of development.

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.