GRAIN – GLOBAL RESTRICTIONS ON BIOMASS AVAILABILITY FOR IMPORT TO THE NETHERLANDS

FINAL REPORT

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Colophon
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EXECUTIVE SUMMARY

OBJECTIVE

The objective of this GRAIN study is to provide better insight in the 'upper' limit of the amount of biomass that can be made available in a sustainable way for the energy supply in the Netherlands. To this end a large number of existing studies have been reviewed, assessing the future global contribution of biomass energy, both from a supply and a demand perspective. In separate studies the competition with the global supply of food for a growing world population and the competition with biomass used a s a source of materials has been analysed. Finally a typical case of a potential candidate country for exporting biomass to the Netherlands, i.e. Nicaragua, has been worked out and an overview has been presented of the criteria and risks involved in exporting/importing biomass-based energy carriers.

FRAMEWORK

The project has been carried out within the framework of the so-called GAVE and EWAB programmes of Novem, the Netherlands agency for energy and the environment. The GAVE programme aims at the inventory of climate neutral GAseous and Liquid Energy carriers with good perspectives for the future energy supply, whereas the EWAB is aimed at the Energy supply from Waste and Biomass. Novem implements the GAVE programme on behalf of the Ministry of Public Health, Spatial Planning and the Environment, the Ministry of Economic Affairs, and the Ministry of Traffic and Public Works. The EWAB programme is implemented on behalf of the Ministry of Economic Affairs.

POTENTIAL CONTRIBUTION

This evaluation shows that the (technical) potential contribution of bio-energy to the future world's energy supply could be very large. In theory, energy farming on current agricultural land could contribute over 800 EJ, without jeopardising the world's food supply. Use of degraded lands may add another 150 EJ, although this contribution will largely come from crops with a low productivity. The growing demand for biomaterials may require a biomass input equivalent to 20-50 EJ, which must be grown on plantations when existing forests are not able to supply this growing demand. Organic wastes and residues could possibly supply another 40-170 EJ, with uncertain contributions from forest residues and potentially a very significant role for organic waste, especially when biomaterials are used on a larger scale.

In total, the upper limit of the bio-energy potential could be over 1000 EJ per year. This is considerably more than the current global energy use of 400 EJ.
However, this contribution is <u>by no means guaranteed.</u>

Crucial factors determining biomass availability for energy are:
1. Population growth, average diets and economic development.
2. The efficiency and productivity of food production systems that must be adopted worldwide and the rate of their deployment in particular in developing countries.
3. Feasibility of the use of marginal/degraded lands.
4. Productivity of forests and sustainable harvest levels.
5. The (increased) utilisation of biomaterials.

Major transitions are required to exploit this bio-energy potential. It is uncertain to what extent such transitions are feasible. Depending on the factors mentioned above, the bio-energy potential could be very low as well, i.e. around 40 EJ.

MAIN FINDINGS ABOUT BIOMASS STREAMS

In table 1 a summary is provided of the main findings of this study with regard to the most important biomass streams which can be used for energy applications.
A distinction is made between the following categories:
I: energy farming on present agricultural areas
II (extensive) energy farming on marginal lands
III: production of raw material for biomaterials
IV: residues from agriculture
V: residues from forestry
VI: manure
VII: organic waste.

These categories are not independent. An increasing demand for biomaterials may imply a larger claim on agricultural land and therefore a lower possible supply of biomass for energy purposes. On the other hand, an increased application of biomaterials will lead to an increased supply of organic waste. Depending on the development of the world population growth and the application of different agricultural production methods both excess and shortage of agricultural land is possible. In the latter case it is quite probable that more agricultural land will be used, for example by using marginal land, or by reducing the forest area. This in turn influences the availability of residues from forestry, or the possibilities to use marginal land for biomass production. All these interactions have scarcely been studied and require further work.

It is important to appreciate that the larger the potential biomass supply is supposed to be the more boundary conditions have to be fulfilled to realise this supply in practice. An assumed large excess of agricultural land presupposes that large parts of the world change to more intensive agricultural practices.

The data in table 1 provide a crude insight in the potential role that various flows of biomass can play for the world energy supply on the long term (2050).
First of all the very large spread in supply results is noticed: between 40 and 1100 EJ. It is very important to realise that **this does NOT mean that the most probable supply figure is somewhere in the middle**. The results and insights from this review clearly indicate that a large potential biomass supply can only be realised after large changes. The larger the supply requested, the larger the changes will have to be.

Table 1: Overview of the potential biomass supply in the world for a number of relevant categories, including the essential conditions and assumptions to realise that supply (HEI: High External Input, LEI: Low External Input).

Category biomass	**Most important assumptions**	**Potential energy supply in 2050**	**Other remarks**
Category I: Energy farming on existing agricultural areas	Potential supply: 0-4 Gha (average: between 1-2 Gha), Average higher productivity through better soil quality: 8-12 dry ton/ha*yr (*)	0 – 870 EJ (average development: 140 – 430 EJ)	Large areas for energy farming require global structural application of HEI production systems and therefore serious changes in the way food is being produced. This category may have zero potential.
Category II: Biomass production on marginal/degraded land	World wide maximum 1.7 Gha. Productivity 2-5 dry ton/ha*yr. (*)	(0) 60 – 150 EJ	Biomass production possibly expensive or non-competitive because of low productivity. This category may have zero potential through competition food supply.
Category III: Biomaterials	Range in the required area for the global additional material demand for biomaterials: 0.2-0.8 Gha. (average productivity: 5 dry ton/ha*yr).	**Minus** (0) 40 - 150 EJ	The demand for biomass in this category must be deducted from categories I and II. In case the existing forest area can supply this demand then the area claim can theoretically become zero.
Category IV: Residues of food production	Depends of yield/residue ratios and total agricultural area. Large fraction of residues required for soil fertility and nutrient supply.	About 15 EJ (estimate from various studies)	Depends on the type of agricultural production system.
Category V: Residues from forestry	Potential of world wide forestry area is unclear: range is based upon literature values.	(0) 14 – 110 EJ	Low estimate: limited use of forestry residues within reasonable boundary conditions for sustainable forest management. High value: technical potential.
Category VI: Manure	Use of dry manure.	(0) 5 – 55 EJ	Low value: global present use. High value: technical potential. Long term utilisation uncertain.
Category VII: Organic waste	Literature estimates, strongly depends upon development stage, consumption and use of biomaterials; includes waste wood and organic fraction MSW.	5 - 50 (+) EJ (**)	Range based upon literature. High value possible with more intensive use of biomaterials.
TOTAL	Lowest value: no areas for energy farming only use of residues. Highest value: intensive agriculture on best soils.	**40 – 1100 EJ (200 – 700 EJ)**	**Maximum range**. Between brackets: average range for the total supply of biomass in a world, which uses bio-energy at a large scale for the energy supply.

(*) Heating value: 19 GJ/ton dry matter

(**) Rough estimate of the supply of biomaterials after use (Feber & Gielen, 2000): the energy supply from biomaterials as waste may vary between 20 and 55 EJ. (See below; this is the material that may be used world wide, excluding cascade use and without taking into account the time period of the utilisation).

Paper:	275 Mton dry matter.
Plastics:	140 – 550 Mton dry matter.
Wood (eg. construction wood):	600 – 2000 Mton dry matter.
Cotton:	30 – 40 Mton dry matter.
Rubber:	10 – 13 Mton dry matter.
Total for biomaterials:	**1100 – 2900 Mton dry matter (about 20-55 EJ)**

ROLE OF ENERGY PLANTATIONS

The largest potential supply of biomass can be realised through energy plantations on existing agricultural areas and on degraded lands. Avoiding conflicts between biomass production for energy purposes and biomass for the world food supply requires a worldwide intensification of agriculture, resulting in higher yields per hectare (both for agriculture as well as cattle breeding). This particularly holds for developing countries. It is still contested to what extent this is feasible, because rationalisation of the agricultural sector strongly depends upon economic development, availability of capital and knowledge, and cultural factors.

The range mentioned in table 1 applies for an average expected increase of the world population to 9.4 billion people in 2050. With a higher growth more land area is required for food production (but also vice versa). The same applies for the average diet, which assumes an average consumption of meat and dairy products. If the food consumption worldwide shifts towards a more protein-rich diet then the potential biomass availability for energy purposes decreases. Particularly the way in which meat and dairy are produced has a strong influence on the potential shortage or excess of land. Large efficiency improvements can be gained by shifting from extensive towards intensive cattle breeding.

Using marginal lands for biomass production will create much less conflicts with the food supply, but the productivity of these lands is much lower. The availability of water will be the limiting factor in most cases. Therefore the contribution of this category to the biomass potential is uncertain (although it would often be quite effective for soil protection).

It can be concluded that the contribution of energy plantations to the world energy supply cannot be calculated with certainty. It is not impossible that a development takes places in which there is no land available for biomass production, or even a situation in which (large) shortages occur. And although this, limited, study could not discuss regional differences in detail, nor various land use types, it is important to realise that part of the agricultural area for food production and cattle breeding also has, sometimes unique, nature functions. A globally more intensive use of land (food production and biomass) may cause conflicts with these nature values. At a regional/local level decisions will have to be made about the pros and cons of biomass production.

ROLE OF WASTE AND RESIDUES

In various scenario studies the residues of food production do not seem to be able to generate a large contribution to the **net** energy potential. This is primarily caused by the need to re-use a substantial part of the agricultural residues to protect the soil quality and maintain a healthy nutrient balance. Particularly important flows are the secondary flows of residues generated during food production processes (such as bagasse during sugar production and rice husks during rice production). No indications are found in the literature, however, that this contribution will become more than 15 EJ at a global scale.

Manure could in theory provide a significant contribution, but the probability that manure will be collected at a large scale for energy purposes is low. This holds in particular for those situations where economic development leads to a much lower preference for this laborious type of fuel. The contribution of manure to the energy potential of biomass therefore remains uncertain.

The contribution of residue flows from forestry is also fairly uncertain. The range of the data in this category varies from 14 to 110 EJ. When much more use will be made of biomaterials the higher estimate seems more probable. On the other hand it is unclear to what extent the present global forest area can maintain a large increase in demand in a sustainable manner. This requires further study. One should not underestimate the contribution from (organic) waste to the total biomass energy supply.

Partly this supply depends upon economic development (with a direct relationship to the waste production per capita) and partly on the fraction of biomass in the waste. In the situation where biomaterials are used more and more the energy supply from of waste streams can increase to more than 50 EJ. Please note that this also depends on the extent to which cascade use of waste streams has been realised: more cascade use leads to less waste.

The total global potential supply of organic waste seems to vary between 40 - 170 EJ.

ECONOMICS

The feasibility and attractiveness of producing biomass for energy purposes also depends upon the economics of biomass energy systems. On the one hand biomass must compete with the (financial) output of other crops. On the other hand biomass must compete with other energy supply options (or options to reduce CO_2 emissions). The study of these interactions falls outside the scope of this study. The issue is how cost developments will or can influence the demand for biomass for energy and material applications and to which point biomass will compete with food production.

A CO_2 tax can strongly improve the attractiveness of biomass as energy source. The same applies for continuing technological development (cultivation, logistics, conversion, end use). It is even conceivable that biomass as CO_2 neutral resource and energy source becomes so attractive that it will be economically more attractive to produce biomass for energy purposes than for food crops. This may lead to very undesirable developments: financially strong parties could drive out poorer landowners from lands used for food production. In this manner a biomass supply is generated at the expense of the food supply of (a part) of the local population. In the extreme case this may lead to (large-scale) migration, more deforestation by landless farmers and non-sustainable agriculture.

But one could also aim at the involvement of the local parties in bio energy projects. Locally generated incomes from energy production (possibly even export) could become a motor for local development, increase in prosperity, and rationalisation of local agriculture. In this type of development process more advantages can be gained at the same time. An example: agroforestry systems in which both wood for materials, residues fractions for energy, as well as food crops are cultivated in an integrated manner.

The way in which biomass production is realised and how bottlenecks can be avoided will strongly depend upon local factors. These aspects should be evaluated per region in more detail.

Nevertheless, in case bio-energy or biomaterials prove to be an expensive alternative for the future world energy and material supply (for example because cheap CO_2 –neutral energy options will be developed, such as large scale CO_2 -storage) the realisation of the biomass potential will become difficult. This definitively applies for the poorer soils with their low productivity. Yet the cultivation of marginal lands is desirable in any case for soil protection or regeneration, water retention, etc. Internalising the ‘external benefits’ in the costs of a project may justify additional financial support.

An important ‘competitor’ to use land for biomass energy production is forestation with the aim of CO_2 fixation. (Re-) forestation has been identified as a (very) cheap option to compensate CO_2 -emissions. Although the monitoring and the accreditation of CO_2 fixed by means of forestation is still being debated, this option may very well compete with biomass for energy purposes, for different land use types. It is also possible, however, that these two CO_2 reduction options partly support each other, depending on the type of land on which they are implemented. This aspect also deserves closer attention.

THE CASE OF NICARAGUA

Two situations have been analysed: (1) wood is converted to fuel in Nicaragua, and (2) wood is transported to the Netherlands and converted there. The resulting final fuel costs were **roughly identical in both cases**. With fuel production in Nicaragua one can expect that the scale advantages are somewhat smaller and because a higher interest rate has to be used the investment costs per unit of fuel produced are relatively higher. When the fuel is produced in the Netherlands the international transport costs of wood play a dominant role. It is interesting to note that ocean transport of wood causes a poorer energy balance, but the overall effect is still acceptable: the total energy output/input ratio in that case is still about eight.

The socio-economic effects of Eucalyptus plantations are positive on all aspects (job creation, BNP contribution and reduction of imports). This particularly holds when individual farmers, who usually belong to the lowest income groups in Nicaragua, cultivate the wood.

If the Netherlands would import 20 PJ of wood from Nicaragua, then one would need an area of about 110 000 hectares (a square of 33 by 33 km), or about 1% of the area of Nicaragua. Whether this area really can be made available for energy farming, remains subject for further research. For the transport of this amount of wood a fairly large logistical system is required, but not larger than the use presently in use by the sugar factories in Nicaragua. The guarantee for ecological sustainability of these systems could be realised through seals, such as the FSC seal for tropical hard wood.

CRITERIA FOR IMPORT

Some of the crucial criteria for bio-energy systems and import chains are:
Cultivation: maintaining soil fertility is essential; recycling of nutrients (particularly when converting biomass far away for the production region) requires special attention. Biomass production should never be detrimental to nature. Another crucial aspect is the sustainable management of water supplies.
Safety and risks: avoid the spread of illnesses and plagues, and avoid large-scale monocultures.
Efficiency: international trade in energy from biomass only has a purpose when this brings an effective reduction of CO_2 emissions. In case the use of biomass in the area of production itself leads to a higher emission reduction (and/or lower costs per ton of CO_2 avoided) then the export of the biomass is undesirable.

RECOMMENDATION

An important recommendation to the Netherlands government about the possible future import of biomass is therefore: increase the knowledge and insights in the possible consequences of large scale import of biomass energy. This can be done by setting up a limited number of pilot projects for the trade in bio-energy, and by monitoring these projects very carefully, supported by research activities. Such pilot projects can also provide a better understanding in how broad the support for these activities is, both in the Netherlands as well as in exporting countries. In the long run much more knowledge and information is required about which regions would be most suited for a sustainable production and trade in biomass energy. It will be necessary to develop and introduce a ‘FSC’ type mark for biomass-based energy carriers.

RESEARCH REQUIRED

There are still a number of crucial research questions in areas such as: economic drivers of land use, competition of biomass with other land uses, and competition with other sources of energy and materials. These interactions need to be studied at local/regional level, taking into account the effect of technological and economical changes in time. In addition there are complex questions in the field of optimizing the allocation of biomass resources and the organisation of biomass import chains.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Annexes

INTRODUCTION

1. BACKGROUND

This project has been carried out within the framework of the so-called GAVE and EWAB programmes of Novem. The GAVE programme aims at the inventory of climate neutral GAseous and Liquid Energy carriers with good perspectives for the future energy supply, whereas the EWAB is aimed at the Energy supply from Waste and Biomass. Novem implements the GAVE programme on behalf of the Ministry of Public Health, Spatial Planning and the Environment, the Ministry of Economic Affairs, and the Ministry of Traffic and Public Works. The EWAB programme is implemented on behalf of the Ministry of Economic Affairs. In the concluding advice of the first GAVE programme (end 1999) the following was stated with respect to the availability of biomass:

- No information on the upper limit of biomass availability has been generated
- The biomass streams in the Netherlands can be utilised much better
- Import offers perspectives, if a leading role is chosen.

The advice to the Ministries: analyse the future optimal use of biomass, on the basis of the insights gained in the earlier GAVE studies.

The response of the Ministries was:

- Indicate how the available biomass at different points of time can be utilised most effectively
- Indicate the possible role of biomass import and which boundary conditions apply
- Increase the insights in the availability and the price of biomass.

On the basis of this response two studies were contracted by Novem: **Optibio** Optimal use of biomass (by KEMA) and **GRAIN** Global Restrictions on the Availability of biomass in the Netherlands (by UCE, this study).

2. OBJECTIVE

The objective of this GRAIN study is to provide better insight in the 'upper' limit of the amount of biomass that can be made available in a sustainable way for the energy supply in the Netherlands, on the basis of existing studies. With this insight an integral, compact and clear overview is formulated of the possibilities, the boundary conditions and the desirability of import of (energy from) biomass.

3. DETAILED OBJECTIVES

To provide better insight in the maximum amount of biomass that can be made available in a sustainable way for the energy supply of the Netherlands, at a price which is affordable for the technology chains identified earlier in the GAVE programme. It will be studied to what extent the availability of biomass is a barrier for the import into the Netherlands.

In order to generate this insight the following questions will be answered:

1. What do the available literature sources mention about global production of biomass and the share of this production which can be utilised for the energy supply at the medium (2020) and long (2050) term?

2. To what extent this potential is affected, positively or negatively, by the demand for biomass as a source of materials, based upon experiences in Europe?
3. What is the result of earlier studies on global land use in relation to the demand for food, population growth, agricultural practices and biophysical production limits?
4. Which sustainability criteria have to be taken into account when importing biomass in the Netherlands?

4. DESCRIPTION OF THE ACTIVITIES

The GRAIN project has been divided into the following parts: a so-called Main Project, four Subprojects, a Review Workshop, and a summarising Synthesis.

Main project: Literature review on the world wide potential of biomass energy.
Partners: **UU-NW&S**, RIVM, Ecofys
Experts: Hoogwijk, Van den Broek, Faaij, De Vries, Bouwman, De Jager.
Objective: Providing an overview of the results of the different studies on the world wide future potential of biomass as an energy source; in which both energy farming and the use of waste streams from agriculture and forestry are included. Discussing and explaining (if possible) of the differences found, on the basis of the scenarios used.

Subproject 1: Possible future world demand for biomass as a source of materials.
Partner: **ECN**
Experts: Gielen, De Feber
Objective: The analysis of the possible future competition between the use of biomass for materials and for energy. The analysis is based upon the experience in Europe. In addition a brief analysis will be provided for other regions of the world. Possibilities for cascade use will be indicated.

Subproject 2: Exploring of the possibilities of production of biomass for energy supply, depending on the biophysical, demographic and socio-economic factors that determine the food supply in the world.
Partner: **WU - PP**
Experts: Wolf, Vleeshouwers, Rabbinge
Objective: The analysis of existing scenarios of global land use in relation to the demand for food, population growth, agricultural methods and en biophysical production conditions.

Subproject 3: First attempt to formulate sustainability criteria about the import of biomass for energy purposes
Partner: **UU-NW&S**
Experts: Faaij, Van den Broek, Turkenburg
Central question: Which sustainability criteria may play a role in the import of biomass in the Netherlands (before or after conversion)?

Subproject 4: Case study in a promising region
Partner: **UU-NW&S**
Experts: Van den Broek, Faaij
Objective: Estimating the costs of energy farming in Nicaragua, taking into account the sustainability criteria of subproject 3.

Organizing a review workshop

Partner:	**UCE**
Experts:	Lysen, Pruiksma
Objective:	Preparing and organising a review workshop in which the draft results of the main project and the subprojects 1-3 are discussed (31 May 2000).

Synthesis of the project

Partner:	**UU-NW&S** + UCE, consulting all partners.
Experts:	Faaij, Van den Broek, Lysen, et al.
Central question:	Providing an overall picture of the availability of biomass for typical GAVE applications in the Netherlands, based upon the different possible roles that biomass can play in the future world energy supply.

The **co-ordination** of the project is in the hands of the UCE (Lysen, Pruiksma).

SYNTHESIS OF GRAIN

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1. INTRODUCTION

This synthesis aims at providing a compact and clear overview of the insights available in the existing literature about the world wide future availability of biomass for energy purposes.

These insights will be based upon summaries of:
1. Estimates of the potential of the contribution of biomass to the (future) world energy supply
2. Global land use for agriculture, forestry, etc.
3. Estimates of the future demand for food, animal fodder, organic materials and feed stocks
4. Possible future developments in the production of food and biomass.

In this synthesis the insights of the different GRAIN subprojects are merged to generate an overall picture. This picture will provide insight in the amounts of biomass that globally could be made available for energy purposes, including the main factors leading to a higher or lower availability. In addition this synthesis discusses the possibilities, boundary conditions and possible barriers for large-scale import of biomass, or energy carriers from biomass, to the Netherlands. This is illustrated by a case study of the export of biomass from Nicaragua to the Netherlands.

Approach

The information and results presented in this study are derived from the existing literature and a general analysis of the available data. It is to be noted that data in the literature very often are based upon model calculations. The wide range of the resulting estimates demonstrates the sensitivity of the various assessments of the global biomass potential.

It is stressed that the present study should not be regarded as a new scenario study or analysis of the global biomass potential.

2. RESULTS OF REVIEW: SUPPLY AND DEMAND OF LAND

2.1 Overview of studies on global biomass potential

In the Main Project seventeen studies on the future global share of biomass in the future energy supply mix have been compared. A difference is made between "**Resource Focussed**" studies, looking primarily at the supply side, and "**Demand Driven"** studies. The studies are compared with regard to their approach and their results. Because the upper limit of the global availability of biomass is treated best in the Resource Focussed studies, we will concentrate on these studies in this synthesis. Figure 2.1 shows the results of the Resource Focussed studies as a function of the year for which the estimate is made.

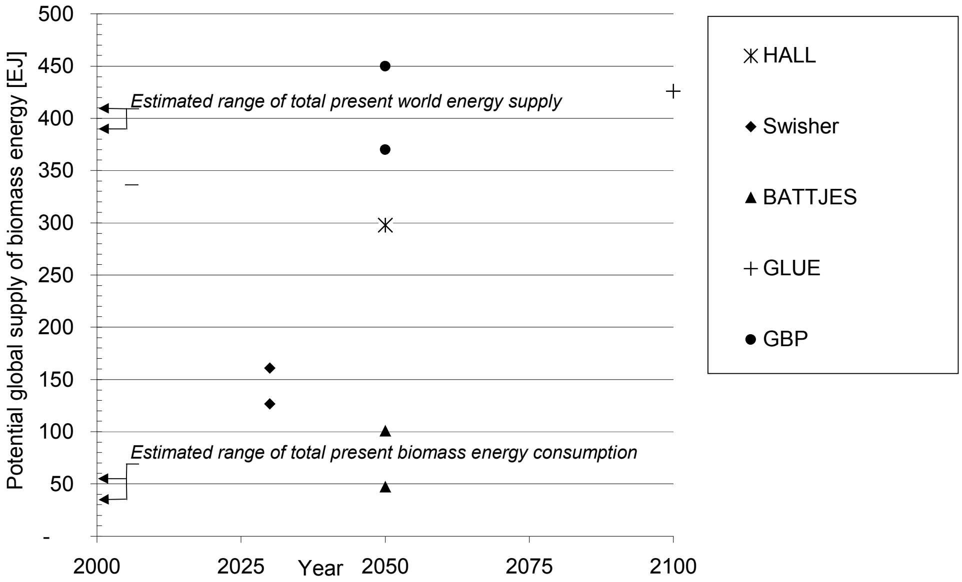

Figure 2.1 Estimates of the potential of the global world wide production of biomass according to different 'resource focussed' studies. (Hoogwijk et al., 2000).

LAND USE FOR ENERGY PRODUCTION

For the production of biomass one needs land area. A conservative estimate of the productivity of perennial crops such as Willow, Eucalyptus or Miscanthus is 8 - 12 oven-dry tonnes per hectare per year. The (lower) heating value of a dry tonne of biomass is around 18 GJ (10^9 joule). The net energy production is about 5% lower, because of the energy used for fertilisers, pesticides, and fuel for machinery. Result: 1 ha can produce 140 - 200 GJ (nett) per year. Producing 1 PJ (10^{15} joule) per year requires 5 000 – 7 000 hectare.

A power plant of 600 MWe in base load (about 7 000 full load hours) with an efficiency of 40% requires an energy input 38 PJ / year, for which 190 000 – 260 000 ha is needed. For 100 EJ ($100*10^{18}$ joule), about one quarter of the present world energy demand 500 – 700 million hectare is required (one third to nearly half of the present area for agriculture in the world and 4%-5% of the global land area, see table 2.1).

To compare: the surface area of the Netherlands is 3.4 million hectare.

The resulting estimates of the resource-focused studies vary by a factor of ten: between 47 EJ/yr (BATTJES) and 450 EJ/yr (GBP250) for the period 2020 -2050. To explain these differences we will analyse the way these results have been achieved, and elucidate a few remarkable results.

Energy crops

A remarkable results is the high contribution of energy crops as estimated by HALL (267 EJ/yr) en GBP2050 (205 EJ/yr) and the low values used in the studies by BATTJES (47 EJ/yr) and DESSUS (15EJ/yr). The large potential for energy crops determined by HALL en GBP2050 can be explained by the fact that both studies assume that in the future a large land area will be available for energy crops. The origin of this land area in both studies is quite different, however. GBP2050 assumed that energy crops could be cultivated on grass lands. The global average production was estimated at 100 GJ/ha/jr; and the total available land at 1600 Mha.

HALL assumed that the required area could be derived from the present area for agriculture, forestry and pasture. He assumed that 10% of that area could be made available for energy crops, leading to an available area of 890 Mha. For the production of energy crops a value of 300 GJ/ha/yr was used for all land types (three times the average yield used in GBP2050).

BATTJES gives a low estimate of the biomass share in 2050, also because the study only focused on energy crops. He assumed that these were cultivated on areas not needed for agricultural crops, according to the scenario used. In the low estimate one also assumed beforehand that energy farming would not be possible in Asia and Africa. The total area required and the average yield are not mentioned in the study, but in another study with the same crop production model an average yield of about 255 GJ/ha/yr was used.
DESSUS used a completely different approach to calculate the potential of energy crops. DESSUS related the availability of land to the population per cultivated area. The total available area was not presented. With a rough estimate of the assumed average production of 170 GJ/ha/yr, a required area of only 88 Mha is the result (10% of the area assumed by HALL).

Residue streams
Quite different estimates for the amount of biomass from animal waste streams were given by HALLl and by the authors of GBP2050. GBP2050 assumed that 100% of the waste streams are available as a source of biomass (54 EJ/yr), whereas HALL estimated this at 12.5% (5 EJ/yr). Also remarkable were the large differences in the use of residue streams of forestry for energy purposes. GBP2050 en DESSUS included the renewable fraction of forestry residues as a source for bio-energy. They determined this on the basis of the present forestry area and the assumption that a certain percentage of that area would not be needed for wood production (leading to estimates of 110 EJ/yr and 86 EJ/yr, respectively). HALL and SCHWISHER assumed that only a limited fraction of the forestry residue streams would be available for energy purposes (14 EJ/yr for HALL).

2.2 Land use at global scale

The world's surface area and its distribution over a number of major categories of use are shown in table 2.1. This classification is rather crude and in fact includes many different types of land use per category (see also the remarks in table 2.1). The present land area for agriculture and pasture, mainly for food production, is about 5 Gha. From this area 3.5 Gha (i.e. 70%) is largely used on an extensive basis, mainly for cattle raising. These data do not include the possibilities to increase this area, for example by improving low-productive or non-productive land through irrigation, terracing, etc.

Table 2.1 Global land area and the major land use categories.

Land use category	**Area Gha (10^9 ha)**	**Remarks**
Agricultural land	1.5	The definition also includes pasture land for intensive cattle raising (such as in the Netherlands)
Pasture land	3.5	Primarily extensively used pasture land.
Forest	4.0	Natural forests as well as production forests.
'Non-productive' land	4.2	Deserts and desert-like land, highlands, glaciers and the areas with built environment.
Total	**13.2**	**Global land area**

2.3 Food production

Expected demand for food

The global demand for food and food products depends on demographical developments (population growth) and the (average) diet of the world population. Estimates for the world population in the year 2050 vary between 7.5 and 12 billion people (5.9 billion in 1998). Recent insights (Groningen University) indicate that the highest estimates may be less realistic and their estimates show a maximum world population of around 9.5 billion people.
The average diet is determined, amongst other factors, by the average amount of food products consumed (such as vegetable, meat and dairy products). A protein-rich diet requires considerable more input of primary agricultural products (grains and grass) because of the conversion losses in the meat and dairy production.

Table 2.2 shows the major results of a scenario study on the future global demand for food (Luyten, 1995). In this study the *total* demand for food is expressed in so-called "grain equivalents". For meat and dairy products conversion factors were used to take the losses into account during the conversion of vegetable to animal material. For meat production this factor on average is around 9 (i.e. an efficiency of only 11%) and for dairy around 3, depending on the type of cattle raised.
The net energy requirements per person do not differ much in the various diets: from 10.05 MJ/person*day for a vegetarian diet to 11.6 MJ/person*day for a protein-rich diet with a lot of meat and dairy products. But the required grain-equivalents differ substantially as a result of the conversion losses: from 1340 to 4200 grain-equivalents per person per day, respectively, for a vegetarian and a protein-rich diet. The present average world diet requires about 2630 grain-equivalents.

The potential spread in the future global demand for food on the basis of these data is fairly large (see table 2.2). With reference to the present consumption of 5 650 Gton even a decrease is possible. A threefold increase is also possible, however. The average situation seems most realistic: an increase of the total demand for food of about 50% in 50 year.

Table 2.2: The potential spread in the global demand for food around 2050.

	Present situation	Minimum demand (vegetarian diet, low population growth)	Average demand (average diet, average population growth)	Maximum demand (protein-rich diet, high population growth)
World population (billion people)	5.9	7.7	9.4	11.3
Diet (dry kg grain-equiv. per person per day	2.6	1.3	2.3	4.2
Total food demand (Gton grain-equiv.)	5 650	3 670	8 240	17 310

Food production systems

The way in which food and food products, agricultural products and animal products are produced strongly differs for the various regions of the world. Table 2.3 presents an overview of the production levels of grain crops in various regions and of their historical development. In Africa for example the average yields are roughly a **factor of five lower** than those in Western Europe. Because of the climatological conditions in the (sub-) tropical climate zones the effective growing season is longer and therefore a higher average yield should be possible compared to the moderate zones. Poverty, lack of capital and knowledge are vital factors to explain the lower yield levels.

Table 2.3: Average annual yields for all grain and grain-like crops for a number of areas in the world and the historical yield growth per hectare.

	Yield (tonnes dry matter/ha*yr)			**Average yield growth/year**	
	1961	**1990**	**1999**	**1961-1999**	**1990-1999**
World (average)	1.35	2.76	3.04	3.3%	1.1%
Africa	0.8	1.18	1.22	1.3%	0.5%
Asia (excl. Russia)	1.21	2.82	3.14	4.2%	1.3%
Latin America (incl. Caribbean)	1.27	2.09	2.84	3.3%	4.0%
Western Europe	2.15	4.74	5.53	4.1%	1.8%

Food crops

Climate, soil, availability of nutrients and water are the primary factors determining the productivity. In the study by Luyten (1995) possible crop yields are calculated with crop growth models, on the basis of a worldwide database of climate and soil data. These models include, amongst other things, the effects of water and nutrient shortages on crop growth. Also included are the effects of non-optimal management methods, and losses caused by diseases and varying harvest methods.

For these calculations a distinction is made between two production systems: a so-called Low External Input (LEI) production system and a High External Input (HEI) system. These systems differ mainly in the way diseases and plagues are combated and in the use of fertilisers. In LEI systems no fertilisers and insecticides are used, and as a result the nutrient supply is ensured by biological nitrogen fixation and by organic manure. The crop growth is often limited by nutrient shortages and because of illnesses and plagues the crop losses are higher than in the HEI system. HEI systems are characterised by the structural application of fertilisers, insecticides and herbicides (chemical and biological).

Another important difference (both for HEI and LEI-systems) is that between irrigated and non-irrigated soils, particularly in drier and warmer climate zones. Shortages of water can seriously reduce the crop yield. Table 2.4 gives an impression of the differences in productivity between HEI and LEI systems on a global scale. Regional differences disappear in this presentation. In practice is is not possible to irrigate all agricultural land and therefore irrigated land will always be a certain fraction of the total area. At present the global irrigated area is 18% of the totaal agricultural area.
If the average increase in productivity of the last 10 years (see table 2.3: 1.1%/yr worldwide) would be extrapolated to the year 2050, then the average global productivity would amount to around 5 tonnes of dry matter of grain-equiv./ha*yr. This value fits fairly well in the yield variations shown in table 2.4. These yield levels are not unreal: large areas in Western Europe and Northern America presently approach the yields comparable with a HEI system without irrigation.

Table 2.4: Calculated average potential grain yields, at a global scale, for four different types of agricultural production systems.

	High External Input system (tonnes dry matter grainequiv./ha*yr)	Low External Input system (tonnes dry matter grainequiv./ha*yr)
Irrigated	16.3	4.6
Non-irrigated (natural rainfall)	6.7	2.5

Meat and dairy products

In the study by Luyten the consumption of meat and dairy has been converted into grain-equivalents (including grass for example), as mentioned above. The losses when converting grains and grasses to dairy and meat are considerable. Luyten uses factors of 3 and 9 (i.e. conversion efficiencies of 11% and 33% for meat and dairy respectively).

Wirsenius [Wirsenius, 2000] discusses the *present* production of dairy and meat in different regions of the world. For dairy production (incl. meat from dairy cattle) he mentions a variation of conversion efficiency from corn (in corn equivalents) of between 5.2 and 19%, for Africa and Western Europe respectively. For meat production a range is given of 0.58 - 1.8 % for beef, 2.8 - 6.4% for pork meat, 4.1-8.3% (lowest value for Latin America) for chicken and 10-18% for eggs. These data reasonably compare with the data of Luyten.

These low efficiencies explain the large biomass production for animal fodder, whereas the resulting animal products (meat and dairy) are just small part of the total diet (see figure 2.2).

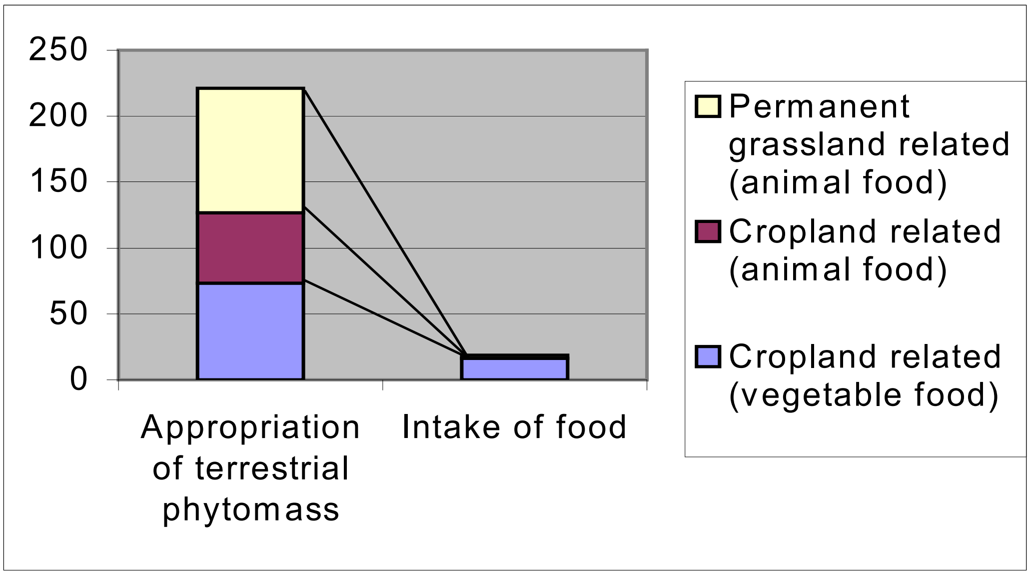

Figure 2.2: Total global energy production via grass and agricultural crops, compared to the energy demand corresponding with the net intake of food by the world population, expressed in Exajoules/year (Wirsenius, 2000).

The above conversion efficiencies vary with a factor of 2 to 4 between the different world regions with the highest efficiencies for Western Europe and North America (without exception). An important explanation for the differences is (again) the intensity of the production systems. Particularly the extensive cattle breeding for meat production shows a very low conversion efficiency of grass to meat. Explanations are:

1. Insufficient quality of the grass.
2. Losses of grass during grazing (through treading on it and because animals cannot reach it).
3. A large fraction of the animal consumption is used for body maintenance and displacements in order to graze. In an intensive system for cattle breeding the conversion efficiency is much higher, because the animals are slaughtered as young as possible, the animals receive good quality fodder. They realize a fast increase in weight, and the energy requirements for body maintenance is limited by staying in closed stables.
   (Note: this does not cover ethical questions, of course).

The differences in conversion efficiency between the different animals are important: one kilogram of chicken requires on average four times less animal fodder than a kilogram of beef. Pork meat lies in between.

These data show that the amount (and type) of meat and dairy in human diets and the way they are produced, are crucial factors to determine the demand for agricultural land at a global scale.

The land required for food production

The combination of the global demand for food and food products on the one hand and the way this food is produced on the other hand, determine the land area required to feed the world population.

This need for agricultural area has been calculated for different world population sizes in the year 2050, different average diets and different agricultural production systems (Wolf et al., 2000). From these data the remaining available land for other purposes (such as biomass production) in 2050 has been derived. These production systems are based upon sets of assumptions for the share in irrigation and productivity per world region (see also table 2.4; Luyten,1995).

Table 2.5 shows a summary of the most important results of these calculations. The data presented are valid for a world population of 9.4 billion people in 2050. With a lower or higher number of people the additional land area increases or decreases proportionally.
It is to be noted that the estimates are limited to the present area for food production (5 Gha, see table 2.1) and also that these estimates do not reflect the distribution of the meat and dairy production. The table clearly shows that uncertainty in potential land area available for bio-energy is substantial. It varies between 4 000 million hectare (1000 times the area of the Netherlands) and zero (in fact a shortage of land, because of the high demand of land in the case of the combination of LEI production with a protein-rich diet).

Table 2.5: The additional amount of land that potentially could be available for bio-energy purposes, for a world population of 9.4 billion people, for combinations of diets and agricultural production methods, and a fixed agricultural area of 5 Gha.

Average global food production system	Vegetarian diet	Average diet	Protein-rich diet
HEI	4.00 Gha	3.16 Gha	1.88 Gha
LEI	2.72 Gha	0.64 Gha	0.00 Gha

2.4 Biomass demand for material purposes

Presently a large volume of biomass is used in the world for material applications. Important examples are papier & board and wood for construction / building purposes. With a growing world population and a gradual average increase in wealth the use biomass for material applications will increase proportionally. It is also possible to apply biomass for much more types of materials. An important group of materials are plastics, which presently are nearly 100% based upon oil as a feedstock. Biomass, however, can be a CO_2 neutral alternative as feedstock. Also for the substitution of cement of metals in the building industry and in the use of biomass (charcoal) as a reducting agent in the steel industry (instead of cokes from coal) in priciple very volumes of biomass can be used. Table 2.6 provides an overview of the order of magnitude of the demand for ‘biomaterials’, both for a ‘business as usual’ development and in case of a much increased demand for biomass for material applications. These estimates have also been translated into their effects on the land area required.

Tabel 2.6: Potential future demand for biomaterials (per year) for the most important material applications. When ranges in biomass amounts and land areas are mentioned: the low value refers to a 'business-as-usual' development and the high value to a development with a much increased use of biomaterials worldwide.

Material	Present material use (Mton/yr)	Long Term Demand (Mton/yr)	Market share bio-mass (%)	Ton bio-mass/ Ton product[a]	Total required biomass (Mton/yr)	Biomass yield (dry ton/ha)[b]	Land area (Mha)
Pulp	175	275	100	2	550	5	110
Petrochemical	200	550	10-100	2.5	140-1400	10	14-140
Wood	350	600-1000	100	2	1200-2000	5	240-400
Steel	550	700	5-100	0.7	25-490	5	5-100
Cotton	20	30-40	100	1	30-40	2	15-20
Rubber	7	10-13	100	1	10-13	2	5-6.5
Total					**2000-4500**		**390-780**

[a]Ton biomass per ton product: this indicates how much primary biomass is required to produce one ton of the product desired. When producing construction wood, for example, 50% is lost during sawing. The sawdust remains available for other purposes, however. In the paper production process around 50% of the wood input is turned into 'black liquor' which can still be used for energy production. In the case of the petrochemical industry there are considerable energetic losses in the different processes.
[b] The yield of biomass for the different material applications differs according to the application. For chemical substances most of the raw biomass can be utilised (such as for syngas or bio-crude), but in the case of cotton only part of the crop is used. Pulp wood, construction wood and wood for charcoal requires roundwood with a minimum size.

Cascade use

It is quite important to realise that a considerable part of this biomass is 'stored' and will be released in a later stage as waste or can be recycled. An exception of course is the use of charcoal in the steel industry. Also: during the production of plastics from biomass conversion losses occur, with the result that not all biomass used as feedstock will finally be available as (organic) waste. But in any case, an increased use of biomass for material applications will lead to an increase in the amount of organic waste.
A related effect is that during the production of (bio-)feedstock more organic waste streams are produced. Generally the same rules apply as for agricultural crops with a certain crop-residue ratio. At the same time one can aim at maximum re-use of organic waste for material applications, toepassingen, leading to a strong decrease in the need for virgin material. In case waste and waste products of bio-material production are used again for material production **the demand for virgin material can nearly be halved**.

When using biomass for CO_2-neutral material applications there are two other positive effects with respect to CO_2 emission reduction:

- Biomass used as a material serves at the same time as carbon storage. Many material applications have a fairly long lifetime (cf. construction wood). This effect has to be added to the replacement of non-CO_2 -neutral materials. At the same time it may take fairly long (40-200 year) before the bio-material is available as waste for energy purposes.
- Use of biomass substitutes CO_2-intensive materials. This effect must also be added to to the possible use of biomass for energy purposes in the waste phase. It must be noted that this effect becomes much less significant when alternative materials are produced by means of CO_2-neutral energy carriers. It may be clear that in the long term there are complicated interactions between the energy and the material supply. It is beyond the scope of this study to discuss the optimal use of biomassa for CO_2 emission reduction in time.

2.5 Global land demand and availability

Land demand

Food production: In section 2.4 it was concluded that the world land area needed for food production can vary between 1 000 million and more than 5 000 million hectares. The differences in diets assumed and the differences in agricultural production systems cause this huge difference.

Material production: For the production of biomaterials we found that the demand for land may vary between 390 and 780 million ha. The majority of the required biomass feedstock refers to wood with a reasonable stem size (pulp, construction wood, and charcoal). Although for some of these applications in principle also grasses and even some types of wastes could be utilised (such as for board materials and pulp), it is reasonable to assume that the majority of biomaterials will be supplied by production forests or through harvests from natural forests. To what extent the existing forest area (4 Gha, but this is including natural forests) may be capable of to supply the extra demand for biomaterials has not been analysed properly yet, and requires more study.
It should be noted that the area of wood plantations in the world is fairly modest; Hall et al. indicate, on the basis of Shell data, an area of 125 million hectare. This is an estimate of the early nineties. An increase in the share of industrial wood plantations can greatly reduce the pressure on natural forests.

Availability of land

As indicated in table 2.1 the total global land area amounts 13.2 Gha. This is distributed as follows: 1.5 Gha agricultural land, 3.5 Gha pastureland, 4.0 Gha forest and 4.2 Gha inproductive land. Changes among these categories are possible, to a certain extent: forest area can be transformed into productive agricultural area, and vice versa. The study by Luyten (1995) indicates, on the basis of model calculations (with amongst others climatological, soil and topographical data) that the agricultural area can increase to 4 Gha and the combines agricultural and pasture area to a maximum of 8 Gha. Of course, this will mainly imply a decrease of the forest area.

Hall et al. provide indications for the potential of cropland in Central-America, South-America, Africa and Asia (excluding China). In 1991 this area amounted 700 million hectares. According to FAO estimates this could become 2 000 million hectare. Roughly 1 000 million hectares are described as ‘problem land’ such as degraded areas not used (anymore) for agriculture. The definition of this type of land is that it is capable to ‘economically produce crops within given limitations of soil and water supply’. Land with too much slopes or very poor soils is excluded.

Hall et al. also provide an indication of the areas of degraded land that may be used for reforestation. For the above-mentioned regions an estimate is given of 2 000 million hectare, of which the majority (80%) are dry, desert-like soils. They estimate that roughly 750 million hectare in practice can be used for reforestation. Although this is a fairly large area, it is to be expected that the productivity of this area will be relatively low.

3. PRODUCTION AND SUPPLY OF BIOMASS

3.1 Energy plantations

The productivity or yield per hectare of energy crops strongly depends upon the type of land on which they are produced. The availability of water is one of the crucial factors.

It is quite probable that in a future world in which LEI-type agricultural production systems dominate (see section 2.3) the biomass production for energy production will be driven towards marginal lands. (Note: this is not absolutely necessary, but it depends upon the economic advantage of energy plantations compared to conventional agriculture or forestry). As a result the average yield per hectare will be lower in that case.

On the other hand, in the case that HEI production systems dominate, there is literally more space for biomass production on better lands. The corresponding yields to produce biomass for energy purposes will then be higher.

In the overview of the literature on biomass potential (the Main Project in this GRAIN study) an indicative relationship is given between the area and the expected yield of perennial crops (such as Willow, Eucalyptus and various grasses). Maximum yields vary between 25-35 dry tons of biomass/ha*yr for the best (and also irrigated) areas in the world, and 3-7 dry tons/ha*yr for marginal lands (above a cumulative area of 4 Gha, see figure 3.1 below).

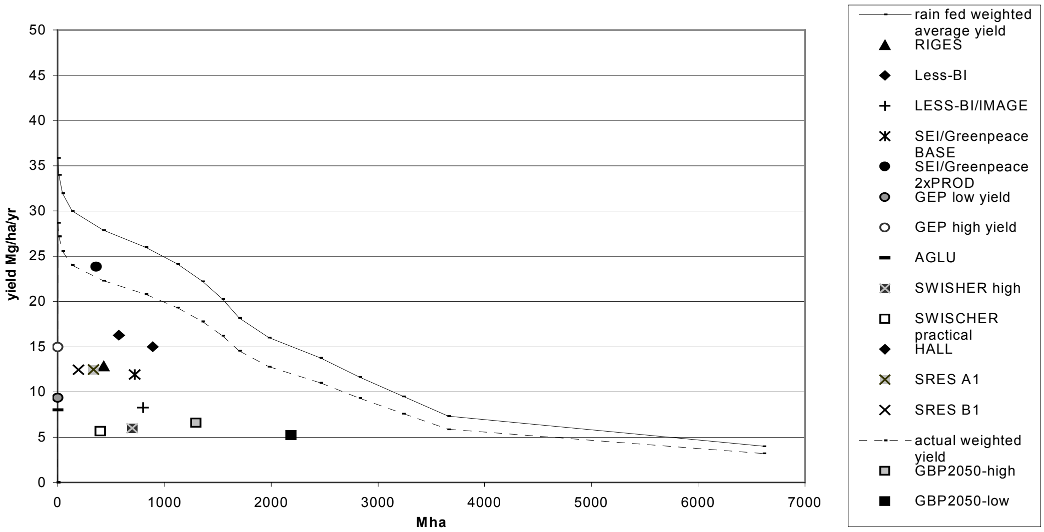

Figure 3.1. Maximum and corrected biomass yields as a function of the land area available for bio-energy production in the world, cumulated with decreasing soil quality (degraded lands are on the right side). The continuous line indicates the maximum yields, whereas the dotted line includes a correction for harvest losses (including for example non-optimal management techniques). Data are taken from the Integrated Assessment Model IMAGE.
The individual symbols represent the average yields of biomass production systems as assumed in the studies mentioned in the legend box.

3.2 Production of biomass residues

Agriculture and forestry in many cases produce organic residues. Examples are straw (from grain) and bark and wood residues from (commercial) forestry for construction or pulpwood.

Residues from agriculture

It is possible to determine the yield/residue ratios for the most relevant crops. These ratios depend on climate and agricultural practices. Yield/residue ratios can also vary in time. A typical example is that when yields increase usually the yield/residue ratios also increase and therefore relatively fewer residues are available. Which part of the residues can actually be used for energy applications depends on local circumstances (soil and climate), agricultural or forestry practices and finally also economic factors. Sustainable soil management and agricultural practices with low external inputs (LEI) as fertiliser, require that more organic matter remains in the soil after harvest. A warm climate leads to a faster decay of organic material in soils. Maintaining proper soil fertility then requires a larger gift of crop residues, and as a result the net available amount of residues decreases. Finally, one of the limiting factors is also whether the costs of collection and transport of residues per unit of energy are not becoming too high.

The total volume of (net) available biomass residues of course also depends upon the total cultivated area, and the average intensity of the production method. A high external input (HEI) system is characterised by more external inputs (such as fertiliser) leading to a higher availability of residues. Also, in a HEI system (with more mechanisation) it is easier to collect residues at reasonable costs. On the other hand, the total area required for a given production is volume is smaller. For a LEI system the total land area is larger, but generally more residues must remain in the field, to maintain proper soil fertility.

In (Hoogwijk et al., 2000) a distinction is made between primary, secondary en tertiary residues. Primary residues are available during the harvest of biomass (food crops, forestry). Secondary residues are generated during the treatment of crops. Examples are: bagasse during the sugar production from sugarcane, sawdust from the wood industry and black liquor as a residue from paper production. In many cases these residue streams are used already for energy production, but often inefficiently, such as when it is only used for the use of the facility itself. Finally there are biomass flows produced as waste streams. These tertiary resides will be discussed separately.

<u>(Primary) Residues from food production</u>
Most of the studies discussing the (potential) availability of primary biomass residues mention a percentage of 25% of the total volume of the residues produced during grain production. No distinction is made between different crops or production methods. Estimates for the amount of primary residues in the total potential biomass supply (in 2050) strongly vary: from about 10 EJ (Greenpeace/SEI) until 290 EJ (IIASA). IIASA, however, also includes Municipal Solid Waste (MSW), dung and secondary residues. Residues from food crops only play a minor role in this study: about 15 EJ, which is assumed to remain constant until 2050. Hall finds a net supply of 'recoverable' residues from food crops of 12.5 EJ. In this figure bagasse (100% available) has been included already.
For grains he assumed a residue/crop ratio of 1.3 ton/ton (of which the assumption is that subsequently 25% of the residue is available for energy purposes).

We conclude that the level of detail of the analysis of the available residues from food crops is relatively limited. At the same time it seems that the authors generally have taken the present situation of the food production as a starting point. The analysis by Luyten has shown, however, that on the long term the way in which food is produced in the world can vary strongly. As discussed an agricultural production system with much external input (HEI) leads to very high production at a limited land area. It is expected also that relatively more residues be produced per hectare, although the residue/crop ratio will be further reduced. On the other side of the scale one finds the LEI system with a lower productivity, a larger land area, higher residue/crop ratios, but at the same time a lower recoverability of the residues. The latter in order to keep a proper nutrient balance in the soil and also because collection is more difficult.

The final trade-off between these two extremes is hard to make with the data collected for the present study and requires considerable more work. It is also to be expected that on the longer term large regional differences between the world regions will remain, because of differences in their development stage and agricultural practices.

On the basis of the data collected in this GRAIN study one can not conclude that the supply of primary agricultural residues can become fairly high. It can be assumed, however, that the supply of secondary residues (such as bagasse) will increase with the increasing demand for food. It is to be expected that these residues will be utilised in the processing industries, noting the efficiency of conversion can be much improved.

Residues from forestry
The total forestry area in the world is fairly large (see table 2.1): 4 Gha. A subdivision is possible between natural forest and production forest, with various categories in between. To determine how much biomass forests worldwide, can produce, is a very complex issue. The annual additional growth of wood can be regarded as the technical potential. The review of studies on the biomass potential provides a range of 14 to 110 EJ/yr for forestry residues. Many studies do not treat forestry residues as a separate category. The low estimate of 14 EJ is from the study by Hall et al. and assumes that 25% of the residues of forestry really are available for energy purposes. Other authors use a percentage of 50%. The value of 110 EJ is from the study by Fischer & Schrattenholzer and probably represents the technical potential.

Manure
The data range in the literature for the worldwide potential energy supply from manure is between 5 and 54 EJ. The first estimate (Hall et al.) includes the fact that a large fraction of the manure supply is required for fertilising or that it cannot be collected. The second value is a theoretical estimate and represents a technical/theoretical potential. Other literature sources do not include manure as a source of energy.
In addition it is to be noted that the conversion efficiency of manure to for example electricity is much lower than in the case of 'solid' biomass such as wood. Many manure streams are wet (often implying a negative heating value) and usually are better suited for biogas digesters. The issue whether manure is a candidate for collection, central conversion and possible large-scale exports remains an open question, particularly for the wet types of manure.

(Organic) Waste
The amount of waste produced in a society depends upon population numbers and economic growth, directly coupled to the use of materials. The biomass part of waste can be regarded as a renewable fuel (see also section 2.4).

Generally very few studies on the world biomass potential include waste. Fischer & Schrattenholzer find a MSW (Municipal Solid Waste) potential of around 50 EJ in 2050, on the basis of simple model calculations and the use of reference data for the waste production per capita. This is roughly five times the estimate given for the present global supply of MSW. In this analysis we also use the estimates by (Gielen & Feber, 2000)

4. POSSIBILITIES FOR IMPORT OF BIO-ENERGY: THE CASE OF NICARAGUA

In order to create a better insight in the possible effects of a large scale import of biomass to the Netherlands, a case study for Nicaragua has been carried out. The main objective was to analyse to what extent it is possible to produce biomass given certain sustainability criteria and within a specified cost range. Nicaragua has been chosen because: (1) it has many typical characteristics of a developing country, (2) commercial energy farming takes places presently, (3) the main project of this GRAIN study found that Latin-America is a promising region for biomass export and (4) detailed data were already available about the country, so a sound analysis was possible within a short time period. The study limits itself to energy crops, because these are expected to provide the biggest contribution, if biomass will play a large role in the future. In terms of sustainability the emphasis is on the effect on the environment, the use of fossil energy sources and the socio-economic impact. The latter consists of: contribution to the BNP of Nicaragua, the amount of import, job creation and distribution of incomes.

Nicaragua is roughly four times as large as the Netherlands, but its population density is ten times smaller. Important characteristics of Nicaragua within the context of this study are: a fairly low income per capita (10 times lower than the Netherlands), a relatively uneven income distribution, a negative trade balance, high unemployment in rural areas and a relatively high investment risk. The total energy consumption is about 200 PJ/yr. Land costs are about Dfl 100/ha/yr and untrained labour is costing roughly Dfl 5 per day.
The expected yield of Eucalyptus is around 13 ton/ha/yr on the present plantations. The costs of cultivating and locally transporting eucalyptus are around 1.7 USD/GJ. To compare: the costs of coal in the Netherlands are around 1.4 USD/GJ, natural gas (for power plants) around 2.2 UD/GJ and the average costs of biomass (without international transport) around 1.9 USD/GJ.

To illustrate the role of the different parameters involved a typical calculation has been made for the production of liquid fuels from biomass, through Fischer-Tropsch synthesis. Two situations have been analysed: (1) wood is converted to fuel in Nicaragua, and (2) wood is transported to the Netherlands and converted there. The resulting final fuel costs were roughly identical in both cases. With fuel production in Nicaragua one can expect that the scale advantages are somewhat smaller and because a higher interest rate has to be used the investment costs per unit of fuel produced are relatively higher. When the fuel is produced in the Netherlands the international transport costs of wood play a dominant role. It must be noted that this is a first estimate based upon the offer of one shipping company. No return cargo has been accounted for.
Optimisation of the logistics will lead to lower shipping costs of wood. Another cost increasing factor is the fact that the size of the ships is limited because for export from Nicaragua the ships have to pass the Panama Canal.

With regard to the environmental effects of the production of Eucalyptus: these are generally positive when related to the energy use of fossil fuels and the land use in case no Eucalyptus would be cultivated. In the case of Nicaragua it was assumed that this land is generally shrub land without economic activity. Water demand and biodiversity may cause problems. This is why it is recommended not to plant trees in places where ground water levels are critical and also to maintain the natural habitats within the plantations. Also it seems necessary to fertilise the plantations lightly to compensate for the loss of nutrients. It is interesting to note that ocean transport of wood causes a poorer energy balance, but the overall effect is still acceptable: the total energy output/input ratio in that case is still about eight.

The socio-economic effects of Eucalyptus plantations are positive on all aspects (job creation, BNP contribution and reduction of imports). This particularly holds when individual farmers, who usually belong to the lowest income groups in Nicaragua, cultivate the wood.

If the Netherlands would import 20 PJ of wood from Nicaragua, then one would need about 110 000 hectares (a square of 33 by 33 km), or about 1% of the area of Nicaragua. Whether this area really can be available for energy farming, remains subject for further research. For the transport of this amount of wood a fairly large logistical system is required, but not larger than the use presently in use by the sugar factories in Nicaragua. The guarantee for ecological sustainability of these systems could be realised through seals, such as the FSC seal for tropical hard wood.

5. Boundary Conditions, Possibilities and Risks for Import of Bio-energy

An overview of the possible criteria for the import of bio-energy is provided in annex 4. Some of the crucial criteria for bio-energy systems and import chains are:
- *Cultivation*: maintaining soil fertility is essential; recycling of nutrients (particularly when converting biomass far away for the production region) requires special attention. Biomass production should never be detrimental to nature. Another crucial aspect is the sustainable management of water supplies.

- *Safety and risks*: avoid the spread of illnesses and plagues, and avoid large-scale monocultures.
- *Efficiency*: international trade in energy from biomass only has a purpose when this brings an effective reduction of CO2 emissions. In case the use of biomass in the area of production itself leads to a higher emission reduction (and/or lower costs per ton of CO2 avoided) then the export of the biomass is unwanted.

Criteria referring to additionality, potential and long-term perspectives have been discussed earlier in this document.

6. DISCUSSION AND CONCLUSIONS

Before discussion the overall findings of this study its limitations should be mentioned first.
The results of this project are mainly based upon the outcomes of other studies and involve no new analyses of the global biomass potential. Several crucial interactions between food, material and energy production have not been analysed. No attention has been paid to economic drivers of land use (competition between energy and food for example) and the way in which more intensive land use influences production methods. Also: the interactions between the energy system, costs of CO2 emission reduction and the competition of bio-energy with other options to reduce greenhouse gas emissions, have not been dealt with. These interactions, however, have a strong influence on the competitive advantage of biomass and the economic rationale behind future biomass use and production. All of these subjects require more study. Also the level of detail of this review study is not sufficient to draw any region specific conclusions. This is necessary before decisions about large-scale trade in biomass can be made.

Overall findings

- The potential upper limit of the contribution of biomass to the world energy supply can be very high, in the long term. The literature review shows a (non-economic) potential of around 1100 EJ, of which the majority is based upon energy plantations on existing agricultural areas. These have to be used in a much more intensive way, particularly in developing countries. Biomass residue flows (from agriculture and forestry) contribute between 40 and 170 EJ, depending on the use of biomaterials. Compared to the present world energy consumption of more than 400 EJ, and even compared to the long-term estimates for the world energy demand (600-1500 EJ), this theoretical potential is very large.
- In order to realise this potential considerable transitions are required, particularly in the way meat and dairy products are being produced. Particularly in developing countries the present productivity and efficiency of food production and cattle breeding is relatively low. Changes in the way agriculture is practised depend upon the availability of knowledge, capital and on cultural factors, which may strongly differ at local level. It is also possible that a shortage of agricultural land may occur, rather than a surplus, when agricultural developments stagnate and the world population increases sharply.
- The net biomass production potential is determined by local factors: physical factors (soil quality, climate, availability of water, land use patterns, etc), and socio-economic factors (costs of land and labour, income distribution, social structure). The differences between various regions in the world are very large. This requires a fairly detailed analysis of the possibilities to produce and possibly export biomass in a sustainable manner, in which the economics of bio-energy systems is a crucial parameter. On the one hand biomass competes with other land use options (food, forestation, nature development) and on the other hand biomass is competing with other energy supply options. There are strong interactions between the economic ‘drivers’ behind land use for food, energy and materials. In many areas of the world biomass can be produced at fairly low costs: costs between 1.5 – 2 U$/GJ are feasible for large parts of the world. Multi-output systems and ongoing development of cultivation techniques can reduce these costs further.

- Large scale production of biomass for energy purposes and possible international trade in (energy from) biomass seems definitely possible, in view of the potential (particularly at the long term). A vital condition for international trade is that the exporting country has a net surplus of bio-energy, to be used as an option for CO_2 emission reduction.
  It is important to realise that technological developments will strongly improve the economics of bio-energy on the long term (both for electricity, fuel and materials) (Faaij et al., 1998, 2000). Large-scale applications and the creation of an appropriate infrastructure (for example for ocean transport) may play a key role. It is not certain, however, which type of use or application is most optimal for the available biomass sources; various applications compete with each other and with other (CO_2-neutral) alternatives. A high conversion efficiency remains an important criterium, perhaps even more than for other energy supply options, because this directly influences the amount of land required to supply the energy services. This aspect requires more study.
- In order to be acceptable as a true sustainable energy option the import of energy from biomass shall have to comply with stringent boundary conditions. This is necessary because it is not impossible that the production of biomass for export of energy may become so attractive economically (for example as a result of carbon taxes in the industrialised countries) that bio-energy will compete directly with food production. On the one hand this would lead to a spiral of unwanted effects, such as the migration of local farmers to land with poorer soils, food shortages for the poorer parts of the population, deforestation and non-sustainable agriculture. On the other hand bio-energy projects (including export) could become the drivers for local sustainable development: involvement of local parties, growth of prosperity and the availability of foreign exchange could result in rationalisation of agriculture, increase in productivity and sustainable soil and water management. The boundary conditions required have ecological, economical and social dimensions, and additionality (in socio-economic and ecological terms) must become a key principle for international bio-energy projects. It seems desirable to create a kind of 'FSC'-seal for (energy from) biomass, In which these boundary conditions at a local level are taken into account.

<u>Summarising:</u> one can conclude from this study and the review of available literature that biomass potentially can provide a very large contribution to the future world energy supply, a contribution even exceeding the present world energy demand. This contribution, however, strongly depends upon a number of factors, which are hard to influence, such as: economic development, population growth, and particularly the way in which food is produced globally. At a regional/local level the possibilities and (potential) effects of biomass production and use may differ strongly. The insights in the possible effects are fairly limited up to now. Bio-energy offers enormous opportunities for a sustainable energy and material supply, but at the same bears large ecological and socio-economic risks (for example deforestation and competition with food supply). It is of utmost importance to make proper demands on large-scale bio-energy projects and international biomass energy trade. For the international trade of biomass it is important to identify regions with a net surplus of biomass compared tom their own energy demand (presently, but also in the future). The export of this surplus should be as efficiently as possible, from the point of view of CO2 emission reduction.

An important recommendation to the Netherlands government with respect to biomass import is to increase the insight in the effects and possibilities of import of biomass. This can be realised for example by initiating, on a limited scale, pilot projects for bio-energy trade, with proper monitoring and additional related research. These pilot projects may provide insight in the level of support for these projects and systems, not only in the Netherlands but also in the (future) exporting countries and in global energy markets.
A better founded insight on the long term is required to find out which regions are suited for sustainable production and trade in (energy from) biomass. Development of a "FSC seal" for energy carriers from biomass is required.

There are crucial research questions in the area of (economic) drivers for lad use, competition of biomass with other land use functions on the one hand and energy (and material) supply options on the other hand. These interactions require further study at local/regional level. The ongoing developments, both technological as wells as economical, should be taken into account. There are also fairly complex issues in the field of optimal allocation of biomass resources and the optimal organisation of biomass import chains.

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ANNEX 1

MAIN PROJECT

A REVIEW OF ASSESSMENTS ON THE FUTURE GLOBAL CONTRIBUTION OF BIOMASS ENERGY

UU-NW&S
RIVM, Ecofys

A review of assessments on the future global contribution of biomass energy

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Content

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1. Introduction

Climate change is by many considered as one of the most serious environmental problems. It is clear that concentrations of CO_2 in the atmosphere will continue rising unless major changes are made in the way fossil fuels are used to provide energy services (Hoffert, *et al.* 1998).

The Dutch government has set up a target of a share of 10% renewable energy sources in 2020. It was expected that biomass and waste have a contribution of 120 PJ of the total of 288 PJ that is aimed to be generated from renewable energy source. Since domestic biomass resources are not sufficient, there are plans to import biomass from other countries. In this perspective, insight in the global biomass energy potential (and the regional differentiation) is required.

It can be stated that the global biomass energy potential equals the globally the photosynthetic process. This process produces an estimated 220 billion dry tonnes of biomass per year [Hall, Rosillo-Calle et al. 1993]. Assuming an average LLV of 10GJ/tonne, this would be about five times the present total energy production. However in practise only part of this is utilisable for energy purposes.
Many studies have been undertaken to assess this global biomass energy potential. However analysts, come up with different conclusions regarding the possible contribution of bioenergy in future primary energy supply. An overview of bioenergy potential assessments – and a critical review of approaches and underlying assumptions– can provide valuable insights regarding the role of biomass in the future global energy system and what factors are crucial for the global bioenergy potential.

This report reviews a selection of studies of global bioenergy potentials. The main objective is:

To discuss the differences of assessments on the future contribution of biomass energy, by discussing and explaining the methodologies and scenarios used in these studies.

In this report a total of 17 studies that assess the global potential of biomass energy are reviewed (see Appendix A for the included studies, their acronyms and references). By taking this set of studies we aim to include studies that are frequently cited and are representative for the total amount of recent global biomass energy assessments. We only focussed on assessments on the global level.

The report is structured as follows: In Section 2 we give a theoretical description of (potential) biomass flows, their competitive users and the land-use competition. In Section 3 we describe the present consumption of bioenergy. Section 4 gives a condensed overview of the approaches of the studies that are included in this report. In this section the various approaches are compared in an integrated and descriptive way. For a more detailed overview of the separate assessments we refer to Appendix B. Section 5 compares the results and attempts to explain the differences. In Section 6 it is tried discuss if, our opinion, the approaches and results are realistic in. Finally Section 7 presents conclusions and recommendations.

2. The bioenergy sources described theoretically

Before reviewing studies that assess the biomass energy potential, we give in this section a theoretical overview is given of the present bioenergy resources.

In Figure 2.1 below, a schematic picture of the flows of terrestrial biomass in the food, materials, and bioenergy sectors –and also in final end use– is given. Aqueous biomass production have been suggested a potentially large provider of biomass for energy purposes. However, this option is not included in Figure 2.1. since it is not explored in any of the reviewed assessments. Therefore we will not discuss aqueous bioenergy production in this report.

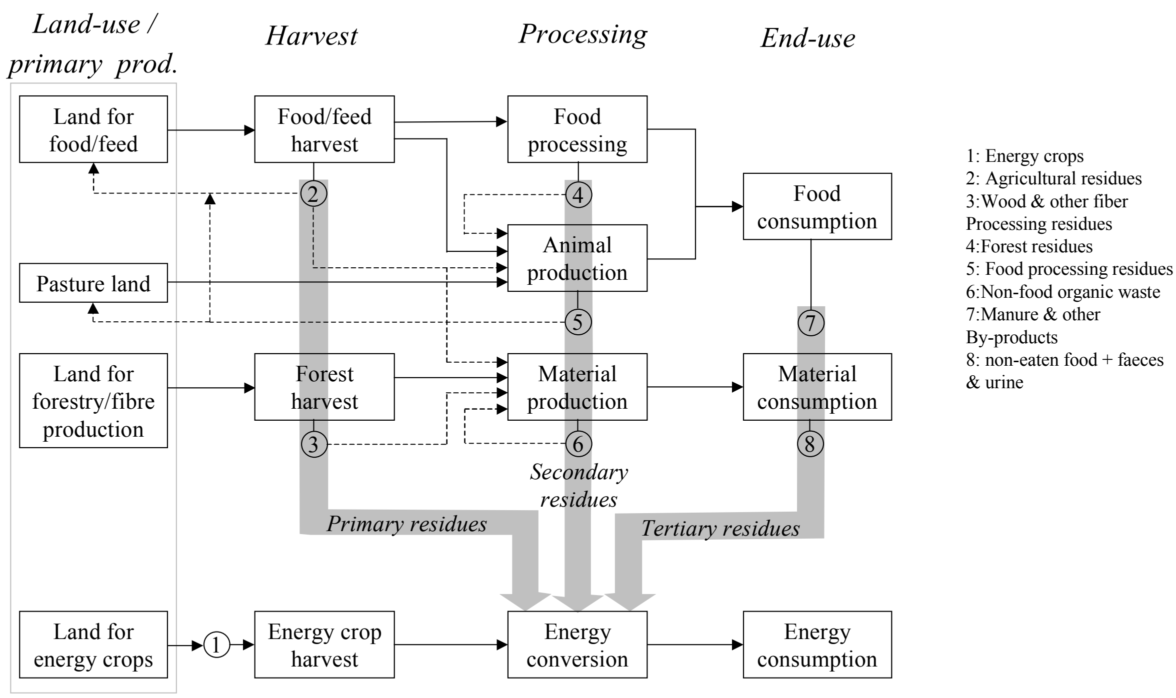

Figure 2.1: Schematic overview of the present terrestrial biomass flows in the food, materials, and bioenergy sectors, as well as in final end use.

Regarding biomass utilization for energy purposes, Figure 2.1 shows that there exists on one hand a competition between land used for energy crops, animal grazing, forestry and food (left part of the figure). Furthermore competition exists between residues (dotted lines). On the other hand there exists a synergy between the purposes (right part of figure) since residue flows can be utilised for energy. The growth in food and forestry products directly implies increased amounts of crop residues with potential use for energy purposes.

Energy crops and the primary, secondary and tertiary types of residues may be defined as follows:

Energy crops: Crops planted on dedicated plantations for energy purposes

Primary residues: residues generated pre- and at harvest of main product, e.g. tops and leaves of sugar cane.

Secondary residues: residues generated in processing to make products, e.g. bagasse, rice husks, black liquor.

Tertiary residues: residues generated during- and post end use (+ non-used products), e.g. demolition wood, municipal solid waste.

To assess the potentials of these bioenergy resources it is important to study what aspects influence the availability of the resources. For this purpose, we express Figure 2.1 as a simplified equation (Equation 2.2). In Equation 2.2 sources are divided into energy crops and residues.

TBS = EC + PFR + SFR + TFR + PAR + SAR + TAR + others Eq 2.2

In which:

TBS = total potential biomass energy supply	TFS = tertiary forest residues
EC = energy crops	PAR = agricultural residues
PFR = primary forest residues	SAR = secondary agricultural residues
SFR = secondary forest residues	TAR = tertiary agricultural residues

The availability of energy crops (EC) and residues (R) in general can be presented in Equations 2.3 and 2.4.

EC = yield * land Eq 2.3

R = total harvested product * ratio between residues and main product * recoverability fraction Eq 2.4

All parameters mentioned in Equation 2.3 and Equation 2.3 are dependent on local factors:

Yield: yields are determined by: solar radiation, rainfall, soil quality and management quality

Land availability: land availability is determined by the requirement of land for other purposes. The latter is influenced by the competitiveness of energy crops with food crops, which differs from site to site, as a results of biophysical and economic factors.

Ratio between residues and main product: the ratio between residues and main product depends on harvest index, improvement of harvest index often been the main improvement in past yield improvement. This development may decrease future ratios between residues and main product.

These underlying dependencies are used in this report for the explanation of the different results.

3. Present bioenergy consumption

Biomass has always been a major energy source for mankind, however the types of biomass used for energy generation and the types of final energy changes over time. To assess the potential of biomass energy, it is important to get insight in the present biomass energy system. In this section an overview is given of data on present biomass energy use. Furthermore the present biomass consumption is described in a qualitative way. First the total biomass energy consumption is discussed, followed by the woody biomass energy and the non-woody biomass energy. In the final parts some recent applications are described.

3.1 Total biomass energy consumption

The contribution of modern biomass energy to the total global primary energy production is included in databases like the IEA [IEA 1998] and has been assessed by Hall, [Hall, Rossillo-Calle et al. 1994], [Hall and Rossillo-Calle 1991]. Roughly the biomass energy consumption can be divided into traditional use and modern use of biomass energy. Former one is generally not included in national statistics. BUN defined modernising as the application of advances technology to the process of converting raw biomass into modern, easy-to-use energy carriers, such as electricity, liquid or gaseous fluids, or processed solid fuels [Hall and Rossillo-Calle 1991]. So the traditional forms of biomass energy include the combustion of i.e. fuel wood and dung for cooking.
It was stated that the biomass energy, particularly in its traditional form is difficult to quantify for mainly two reasons. (i) Biomass is generally regarded as a low status fuel, the “poor” man’s fuel, and thus is rarely included in national statistics. (ii) Difficulties in measuring, quantifying, and handling this dispersed and variable energy source, together with the low efficiency of use, results in little final energy being obtained. .
However based on many national statistics and other country based data, the Biomass Users Network has given a country based overview of the present biomass energy consumption. Figure 3.1 shows the present biomass energy consumption estimated by BUN for four regions; OECD/Europe, Africa, Latin America and Asia.

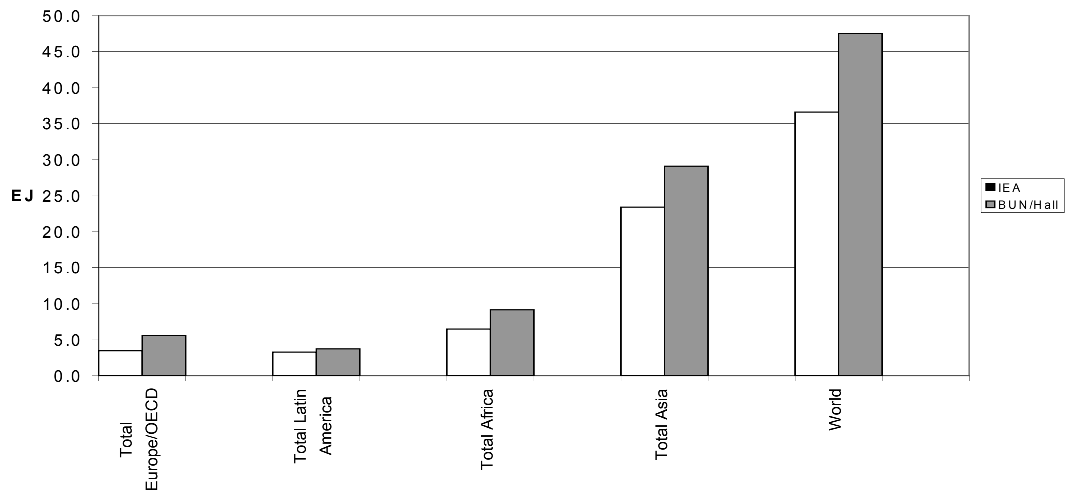

Figure 3.1: Total present biomass energy consumption according to IEA (1995) and BUN/Hall (1989) for four regions and the world.

Figure 3.1 shows that the data from BUN/Hall are higher compared to the IEA. Figure 3.2 shows the share of biomass assessed by IEA and BUN/Hall referred to 1995 total energy consumption according to [IEA 1998] (344 EJ).
According to BUN as well as IEA, biomass energy contributes significantly to the world's energy supply in 1995, 35 – 47 EJ/yr (10% – 14% of total global energy supply in 1995). This number can be compared with the World Energy Assessment 35 – 55 EJ/yr (9 – 13%) [Turkenburg 2000].

The WEA furthermore stated that the modern use of biomass energy, i.e. biomass to produce electricity, steam and biofuels mainly can be estimated at 6-7EJ/yr. This biomass is considered to be fully commercial. Although this does not presents the total amount of commercial biomass since part of the traditional biomass may also be commercial. There are no data on the size of the market. WEA estimated the total commercial use of biomass in 1998 between 10 and 20 EJ.

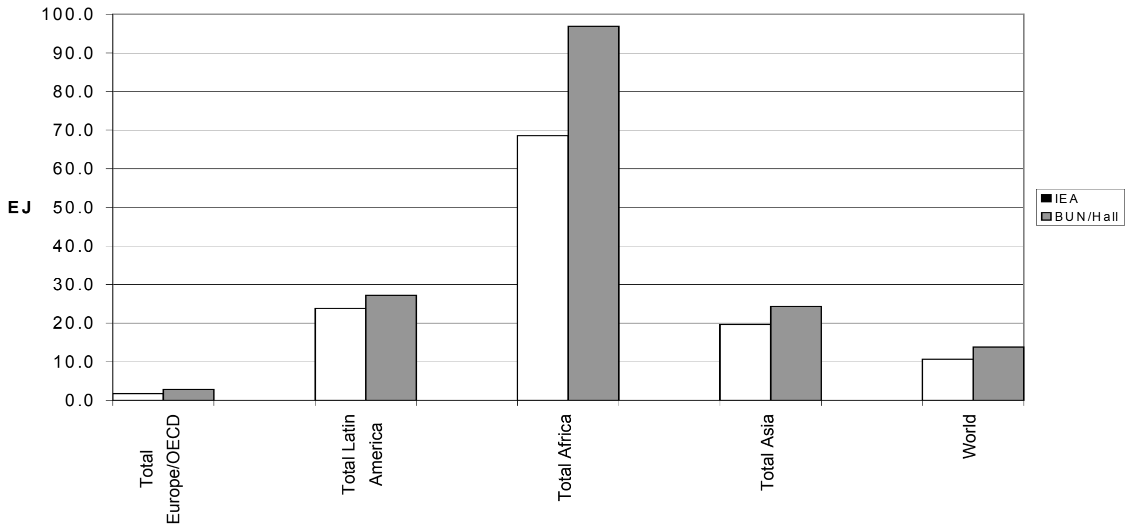

Figure 3.2: the share of biomass energy consumption assessed by IEA and BUN/Hall referred to 1995 total energy consumption according to [IEA 1998] (344 EJ).

3.2 Woody biomass consumption

The Wood Energy Today for Tomorrow of the FAO is a project that collects, reviews and collates existing information and data on wood fuels and its related energy aspects at national level through the preparation of "Regional studies". The main aim of these studies is to overcome the shortcomings encountered in the main wood energy databases and to fill the main data gaps. The study has been done for four regions:

- OECD/Europe
- Asia
- Africa
- Latin America

The final report on Latin America has not been published. However we used data on Latin America, only the analyses were lacking.

Table 3.1 shows the total woody biomass energy consumption according to the WETT reports in 1995 for four regions in EJ.

	OECD/Europe	Africa	Latin America	Asia	World
Wood fuel consumption (EJ)	4.6	4.4	2.9	9.7	21.6

Compared to the total biomass energy consumption presented in Figure 3.1, the woody biomass part contributes around 50% of the total biomass consumption. In developing regions, the woody biomass part contributes to almost 100%.

Below the data are discussed in a qualitatively matter per region.

OECD/Europe [Broek 1997]
The type of wood fuel used among the countries varies largely among the countries. The share of black liquor is large in countries that have a large pulp and paper industry, like Sweden and Finland (about 50%) and Canada (about 60%). The average share of black liquor in total wood fuel consumption was less than 20% for EU-12 and less than 30% for EU-15. The USA and Canada get almost 40% of their wood energy from black liquor.
It was concluded that wood energy consumption in the EU is still mainly a household matter (60 – 70%). For the USA and Canada no figures were given, however, it can be assumed that this contribution is less, since the black liquor consumption in the industrial sector is much higher.

Asia
For Asia two reports that assess the wood energy today and tomorrow are circulating; one by the FAO [Lefevre 1997] and one prepared by RWEDP [RWEDP November 1997].
RWEDP stated that the wood fuel consumption consists of woody biomass, i.e. stems, branches, twigs, etc., and saw dust and other residues from logging and wood processing activities, was well as charcoal from these sources.
Wood fuels are consumed mainly by rural populations though substantial amounts are also consumed in most towns and cities. The largest part of the consumption is accounted for by households, however, also numerous industries and services are based on woodfuels. This was also shown by [Lefevre 1997], who presented a contribution in the household sector between 11 – 97%, with an average for the thirteen countries of 71%.

Africa [Amous 1999]
In Africa, the woodfuel consumption is highly concentrated. In 1994, 5 countries (Nigeria, Ethiopia, South Africa, Tanzania and Congo, the Dem, rep.) , contributed for around 50% of the total African wood energy consumption.
The consumption in the household sector represented more than 86% of total African woodfuel consumption. The industries contribute 9.5% of total African woodfuel consumption. However, it was stated that this might be slightly underestimated. The woodfuel consumed in Africa originated from fuelwood (81.5%), followed by charcoal (18.1%) and black liquor (0.4%).

3.3 Non-woody biomass consumption

Although wood fuel is the predominant biomass energy source, in many poorest nations it is not always the case [Hall and Rossillo-Calle 1991]. The amount of energy from burning dung and agricultural residues in India (1985) in the residential sector was comparable with the use of wood fuel. Furthermore the use of secondary agricultural residues like bagasse and rice husk in the industrial sector have large contribution. Especially since the use of bagasse in the sugar mill industry in some regions is 100%. Rice husks are also used in other industries next to the rice peeling industry, like briquetting [Koopmans 2000].

Regarding the non-woody biomass energy consumption, there are no recent databases or reports available that assess the present non-woody biomass energy consumption. However, databases like IEA and BUN include the use of non-woody biomass, however, do not specify the contribution of non-woody biomass.

However, a simple estimation already shows that the contribution of non-woody biomass may be very large. When assuming a 95% use of bagasse and a 80% use of rice husk in all regions, the primary biomass energy used is 4 EJ/yr, a 50% use of bagasse and 40% use of rice husks results in 2 EJ/yr. The highest contribution is from Asia (2.5 EJ for the high estimation).

4. Overview of approaches of the reviewed bioenergy assessments

This section provides a condensed overview of the approaches in studies on global bioenergy potentials that have been reviewed. Appendix A relates the acronyms used in this report to main references of the corresponding studies. A more detailed overview of the studies is found in Appendix B.

4.1 Characteristics and general approach

A characterization of the studies according to the general approach, the timeframe and the geographical aggregation used, is given in Table 4.1. In this report we categorised the studies that assess the future contribution of biomass energy in two classes (see Figure 4.1): (i) demand driven assessments that study the biomass energy production within the context of a prescribed final energy end-use demand and the competition with other energy supply sources (demand side), and (ii) resource focused assessments that focus on the total potential bioenergy resource base and the competition between the resources (supply side). It is obvious that the biomass energy potential depends on both the competition between resources and the competition between alternative energy sources. Theoretically, to assess the biomass energy potential, both demand and supply side needs to be included, which pleats for a study that cannot be categorised as pure "Resource Focus" or "Demand driven", but uses an approach that start at one side and take into account the whole chain. However in practise it seemed that most studies only focussed on demand or supply side.

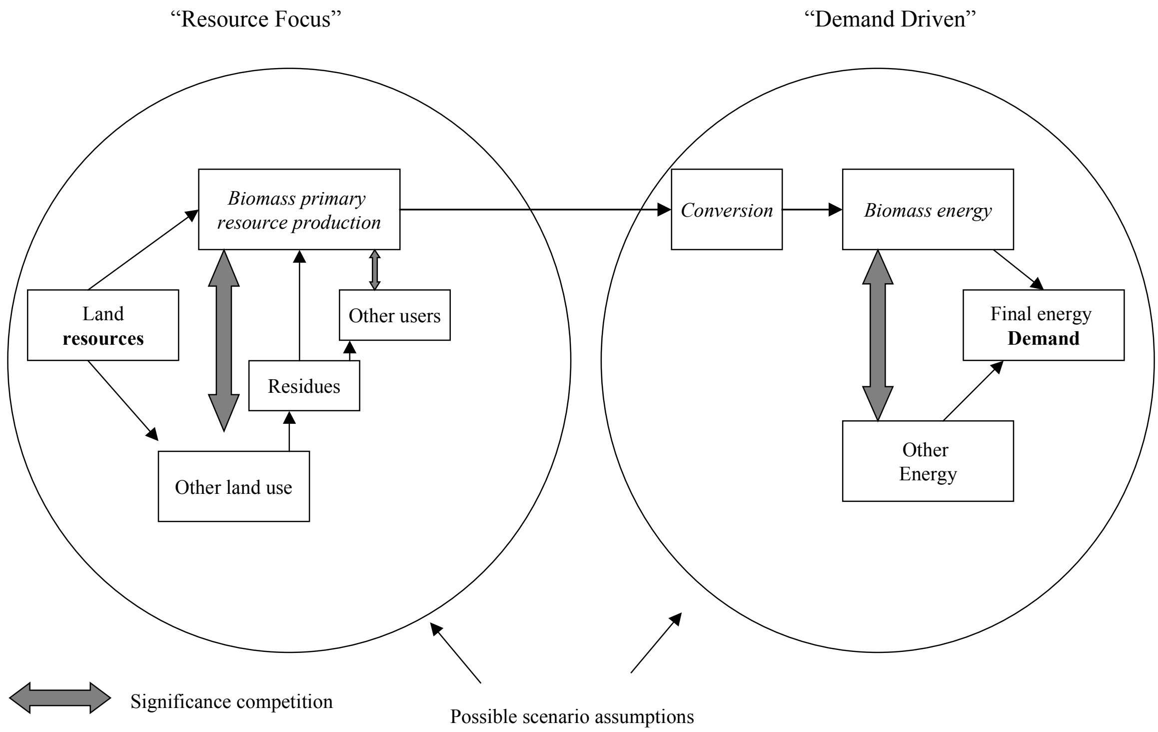

Figure 4.1: Schematic presentation of classification used in this report among assessments of future contribution of biomass energy "Resource Focus" and "Demand Driven".

Since the studies discuss the global potential contribution of bioenergy in the context of energy system transformation and climatic change mitigation, the timeframe is typically 50 to 100 years.

Table 4.1: Approach, time frame, and geographic aggregation used in the reviewed bioenergy assessments

	Study	Characteristics				
		Approach	Time-frame	Geographic aggregation	Resource focused	Demand driven
1	WEC94	Expert Judgment and per capita forecasting based on present consumption	1990-2020	9 regions		x
2	GEP	Energy Economy model, six scenario variants three types of cases	1990-2100	11 regions		x
3	SEI/Greenpeace	Energy Economy model based on Edmonds and Reilly, IPCC based scenario focus on fossil free energy system in 2100.	1988-2100	10 regions		x
4	AGLU	Integrated land use/energy-economy model Edmonds and Reilly, IPCC based scenario	1995-2095	11 regions		x
5	SWISHER	Literature based (Hall) bottom- up calculation	2030	20 regions	x	
6	USEPA	Not integrated land use/energy-economy model based on Edmonds-Reilly	1985-2100	6 regions	x	x
7	SØRENSEN	Bottom-up maximum limit calculation, energy-economy model	2050		x [i)]	x
8	HALL	Literature based bottom-up calculation	1990	10 regions	x	
9	RIGES	Bottom-up maximum calculation (Hall), energy-economy model, IPCC based scenario	1985-2050	11 regions	x [i)]	x
10	LESS-BI	Scenario extension of RIGES by using bottom-up calculations	1990-2100	11 regions		x
11	LESS-BI / IMAGE	(Integrated) land use/energy-economy model by using LESS-BI	1990-2100	13 regions		x
12	BATTJES	(Integrated) land use/energy-economy model + expert judgment	2050	13 regions	x	
13	GLUE	Land use/energy-economy model based on Edmonds-Reilly. Further bottom-up calculation of resources	1990-2100	10 regions	x	
14	SHELL	Not documented	2060	world		x
15	GBP2050	Bottom-up calculation by using land use model of IIASA	1990-2050	11 regions	x	
16	SRES	(Integrated) land use/energy-economy model, IPCC scenario	1970-2100	13 regions		x
17	DESSUS	Literature bottom-up calculation	1990-2020	22 regions	x	

[i)] These studies have an upper limit of biomass energy availability for their demand driven scenario, based on a resource focus approach.

The major underlying driving forces are (regional) population growth and economic development, together with assumptions about technology development, energy system transformation and changes in the energy intensity of economic activity.

In demand driven assessments, where the driving forces create a demand for bioenergy, assumptions about non-biomass energy technologies are important for the ultimate demand for bioenergy. Examples of this is found in the SEI/Greenpeace study, where solar and wind energy systems account for a rapidly increasing share of primary energy supply from 2030 up to 2100, and in the GEP study where e.g., the two C scenarios explores widely different paths for nuclear power –and consequently different demand for other primary energy sources such as bioenergy.

In resource-focusing assessments the driving forces for energy crops determine the competing demand for land from other sectors such as agriculture and forestry. For residue availability the driving forces determined the amount of residues that is generated in these sectors based on expected food and forestry production.

4.2 Bioenergy sources

Table 4.2 accounts for the bioenergy sources considered in the studies (see also figure 2.1 in section 2). As can be seen, not all studies offer complete assessments. In some cases, exclusion of certain bioenergy sources is explicitly motivated (e.g., municipal waste is excluded in SEI/Greenpeace, with reference to concerns about toxic emissions from incinerators and insistence on material reuse and reduction policies). In other studies bioenergy sources are excluded without explicit motivation.

The indication of completeness in table 4.2 is somewhat problematic. A study can be indicated as considering a specific bioenergy source without performing a complete assessment of that source. For example, the HALL, RIGES and LESS-BI studies are indicated as considering food processing residues. However, only sugarcane processing residues (bagasse) are considered. Furthermore, since bagasse is generated in both cane-sugar and cane-ethanol production, utilization of bagasse is acknowledged in table 4.2 as consideration of two categories (2 and 8). The RIGES and LESS-BI studies are also indicated as considering categories 4 and 7, thanks to consideration urban refuse in industrialized countries (LESS-BI includes also developing countries after 2050). However, since faeces and urine is not included in the urban refuse category, and since approximately 85 percent of the global population will live in developing countries in 2050 (although potentially generating less urban refuse per capita), especially the RIGES is far from performing a complete assessment of categories 4 and 7.

More detailed information about how the reviewed studies have treated different bioenergy sources is given in appendix B.

Table 4.2: Bioenergy sources considered in the studies. The numbers refer to categories of bioenergy sources, as presented in figure 2.1 in section 2.

	Study	Bioenergy sources considered [iii]								
		Traditional bioenergy	Energy crops	Primary residues		Secondary residues			Tertiary residues	
				2	4	5	7	3	8	6
1	WEC94	x	x	x	x	x				x
2	GEP	x	x	(x)[i]	(x)[i]		(x)[i]	(x)[i]	(x)[i]	(x)[i]
3	SEI/Greenpeace	x	x	(x)[i]	(x)[i]		(x)[i]	(x)[i]		
4	AGLU	x	x	x						
5	SWISHER		x	(x)[i]	(x)[i]		(x)[i]			
6	USEPA		x							
7	SØRENSEN		x		x	x	x	x		
8	HALL	x[ii]	x	x	x		x	x	x	
9	RIGES	x[ii]	x	x	x		x	x	x	x
10	LESS-BI	x[ii]	x	x	x		x	x	x	x
11	LESS-BI / IMAGE	x	x	(x)[i]	(x)[i]		(x)[i]	(x)[i]	(x)[i]	(x)[i]
12	BATTJES		x							
13	GLUE	x		x	x	x	x	x	x	
14	SHELL [iiii]	?	?							
15	GBP2050		x	x	x		x			x
16	SRES		x	x			x			
17	DESSUS		x	x	x					x

[i)](x) indicates that the category is implicitly considered, via reference to another study that considers the category.
[ii)] Indicates that traditional bioenergy is considered as a source for production of modern energy carriers
[iii)] See Figure 2.1: 1: Energy crops 2: Agricultural residues 3:Wood & other fiber processing residues 4:Forest residues 5: Food processing residues 6:Non-food organic waste 7:Manure other By-products 8: non-eaten food + faeces & urine
[iiii)] It should be noted that the description of the approach of SHELL is marginal.

4.2.1 Energy crops

All studies consider energy crop production. The bioenergy potential of energy crops is a function of land availability and yield level (see Eq. 2.3). Table 4.3 presents the amount and type of land that is assumed to be available for energy crop production in the different studies.

<u>Land availability</u>

In GEP, SEI/Greenpeace and LESS-BI land availability is not assessed and used as input in the modelling. Instead, land use for bioenergy is a *result* of assumptions about total bioenergy supply, plantation contribution, and yield levels in energy crops production. For LESS-BI-IMAGE, this can be explained by the fact that one of the objectives was to assess the impacts of large-scale global utilization of biomass on regional land cover. For this purpose, the LESS-BI data on local production and import/export of energy carriers was implemented in IMAGE. In this way it was possible to precisely mimic the LESS-BI regional energy carrier mix, in order to evaluate the LESS-BI assumptions with respect to land use.

In GEP, land requirements for bioenergy is roughly outlined in a post-scenario feasibility test[1]. Based on this test the authors acknowledge that the combined requirements for bioenergy and food production in their most biomass-intensive scenario variants (A2 & A3) ”…stretch future land requirements (and land use changes) to their ultimate limits”. The SEI/Greenpeace study acknowledges that land use considerations impose limits to the maximum penetration of biomass energy sources. It is emphasised that: “...land availability for biomass energy will depend on the ability of improved agricultural productivity, and the recycling and reduction of wood and paper products...to reduce competition for sustainable land”, however SEI/Greeanpeace only make post-scenario feasibility checks regarding land availability.

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[1] Assumptions about residue contribution and biomass yield level is based on the original LESS-BI study.

Table 4.3: Area and type of land dedicated to energy crop production in the studies.

	Study	Type of land used for bioenergy	Area used for energy vrops production (Mha)		
			2025	2050	2100
1	WEC 94	Surplus cropland in industrialized countries i)	90+	90+	90+
2	GEP	Not clearly specified ii)		390-610 iv)	690-1350 iv)
3	SEI/Greenpeace	Not clearly specified iii)		206-480	326-721
4	AGLU	Cropland	350	570	740
5	SWISHER	10% of global crop, forest and woodland area. Marginal land in developing countries.	400-700 v)		
6	USEPA	10% of global crop, forest and woodland area	n.a. vi)	n.a vi).	n.a vi).
7	SØRENSEN	10% of cropland in areas with surplus cropland. 50% of pastures in all regions i		(758) 159 vii)	
8	HALL	10% of global crop, forest and woodland area ii			890 viii)
9	RIGES	Degraded land in developing countries, and excess cropland in industrialized countries.	369	429	-
10	LESS-BI	See RIGES	83	385	572
11	LESS-BI / IMAGE	Suitable land used for plantations is a model output.	191	448	797
12	BATTJES	Set aside land, with addition of 10% of agri area in dev. regions in the high estimate		185-395 ix)	
13	GLUE	Arable land			
14	SHELL	Not specified			
15	GBP2050	Grassland, changes in land-use were calculated by IIASA's Basic Linked System of Models.		1296 - 2185	
16	SRES	Suitable land used for plantations is a model output.	A1: 125 B1: 99	A1: 374 B1: 268	A1: 334 B1: 194
17	DESSUS	Depends on population density is areas, with a maximum of 10% of cultivated land in areas where density is low			

i) 90 Mha for industrialised region, developing region not specified
ii) Land requirements for energy crops production is compared to availability of potential arable land, as defined and estimated by FAO (Alexandratos 1995).
iii) Indicates that degraded land appropriate for plantations is abundant. Ref. to (National Audubron Society 1991)
iv) Area requirement estimated for the most biomass-intensive of the six scenario variants, with varying residue contribution
v) 2030
vi) Land area is not reported. However, biomass potentials are estimated based on three different productivity levels and an area of 556 Mha (10% of crop forest and woodland area)
vii) The potential area is 758 Mha. On average, 21% of this potential is used: 159 Mha.
viii) No specific year for the assessment is given in HALL study
ix) Calculated based on 30% efficiency in electricity generation and using global average 2050 yield level in IMAGE modeling of LESS-BI bioenergy land requirement (Leemans, *et al.* 1996).

USEPA, SØRENSEN, HALL, RIGES, SWISHER, GBP2050 and BATTJES assume that a certain share of land dedicated to food and fiber production today can be used for energy purposes. This can be interpreted in at least two ways: (i) productivity is expected to grow faster than demand in these sectors, and therefore land becomes available for other purposes such as energy crops production, or (ii) the production is more intensive, so land is available for other purposes. The SØRENSEN, HALL and BATTJES study afterwards explore the feasibility of this assumption (post-scenario feasibility check), the USEPA study does not.

In the studies where land availability for bioenergy is assessed explicitly, the focus is on surplus cropland in industrialised countries and marginal/degraded land in developing countries. The use of surplus cropland for energy crops production is regarded a new source for farm income in industrialised countries [HALL, SWISHER].

In Figure 4.2, the data on land use for energy crops production from table 4.3 is presented together with estimates of future land requirement for food and feed crops production. As can be seen, the bioenergy sector in some studies evolves into a land-using sector of the same order of magnitude as the food sector.

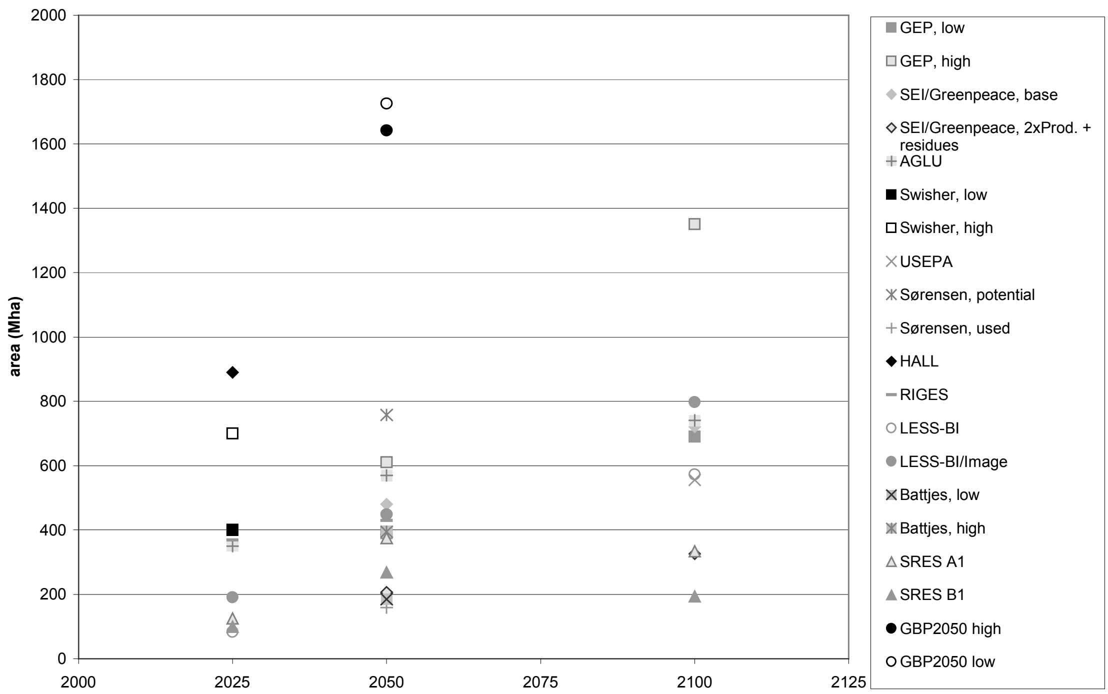

Figure 4.2.: Global land requirements for food and bioenergy: historic development and scenarios for the food sector up to 2100, and land assumed to be used for energy crops production[2].

In most studies, development of the food and materials sector is exogenously defined, the sectors are evolving according to specific assumptions. The bioenergy sector evolves *in parallel*, utilizing residues and land not used for food or fibre production. Thus, even though residue flows in the food and materials sectors are guided to bioenergy uses, and land is used for energy crops production, the expanding bioenergy sector by definition does not affect the food and materials sector.

[2] data from table 4.3

In the AGLU study, it is modelled how prices drive land allocation between food and bioenergy crops. Unfortunately, only baseline scenarios –i.e., scenarios in which no CO_2-abatement occurs– are explored. This means that the energy price does not increase to the point where bioenergy becomes more competitive than food on at least part of the land. The expansion of areas used for bioenergy is acknowledged as implying continued pressure on forests and unmanaged ecosystems, rather than competition with food production.

It is interesting to compare LESS-BI and LESS-IMAGE. The second one reassessed the land availability assumptions of the first. Both studies assume the same potential for energy crops, but differ in the underlying assumptions regarding yield and land requirement. The resulting land requirements in LESS-IMAGE was estimated to be 50% higher than in the original LESS-BI study. This caused deforestation and a competition with food demand. LESS-BI - IMAGE studies the scarcity of land in a way that the model allocates land for food and land for energy crops in the same time step. Preference is given to land with the highest potential productivity for specific crops. When it is not possible to satisfy the demand for both food (fiber) and biomass for energy purposes, after several reallocations, preference is given to energy crop demand.

The reason for this is that the objective of the study was to evaluate the consequences of a certain supply of biomass energy (i.e. as assumed in the original LESS-BI study). Since there is no feedback between land allocation and the energy model the demand for energy crops cannot be adapted to the land availability[3].
None of the other studies treat the bioenergy sector and other land uses in an integrated manner.

With the present approaches, analysts *avoid* rather than *analyse* the competition for land between different land uses. As noted earlier, surplus cropland in industrialised regions and degraded land in developing regions are suggested as suitable for energy crop production. The rationale is that targeting such areas for bioenergy would limit the risk of competition with food production.

Yield of energy crops
Figure 4.3 below presents the global average yield levels in energy crops production, which is used in the studies[4]. Yield levels can vary between regions and over time. Details on regional yield levels –and their changes over time– are reported in appendix B. In the integrated land use/energy-economy models (LESS-BI – IMAGE, BATTJES) the yield level is a function of the model parameters determining productivity (e.g., soils, climate, agronomic practice) and the distribution of energy crops production over suitable areas. Other studies make assumptions about regional yield levels based on the present experiences in fiber and energy crops production.

[3] it is aimed to include a feedback in a next version of IMAGE
[4] For assumptions made regarding energy value is referred to Appendix C

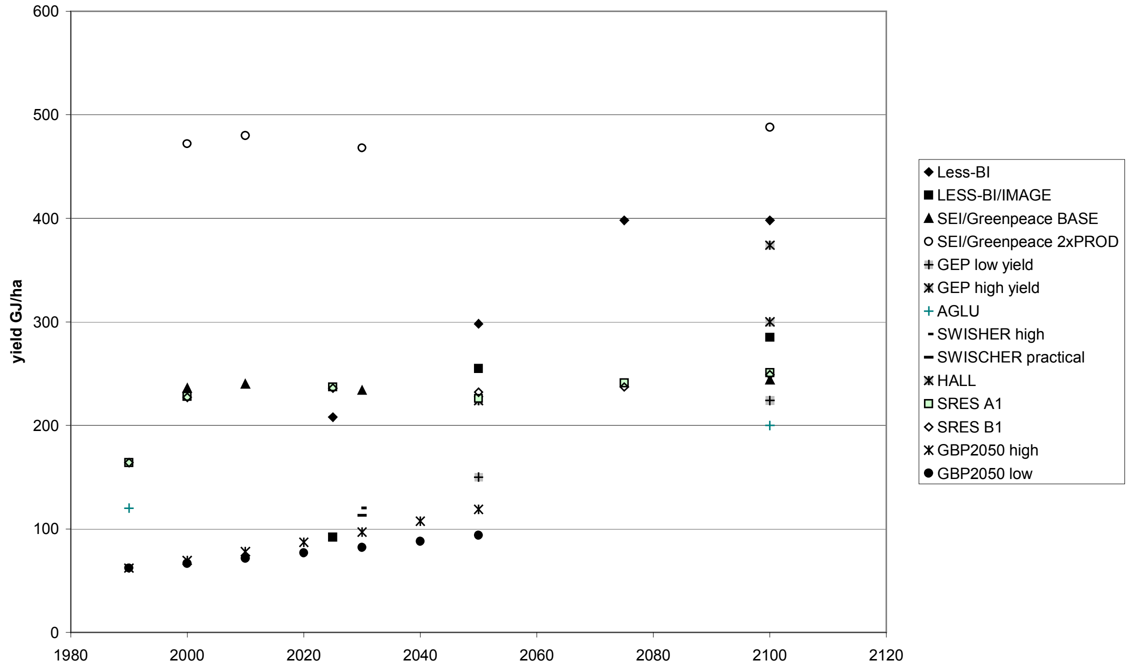

Figure 4.3: Global average yield levels assumed in the studies. [5]

4.2.2 Biomass residues

In section 2, an overview is given of the present terrestrial biomass flows in the food, materials, and bioenergy sectors, as well as in final end use. The residue flows, induced by the human use of biomass in the three sectors, were categorised as being primary-, secondary- and tertiary residues (see figure 2.1 and table 4.2).

Residues from the food sector consist of crop harvest residues (no 2 of Figure 2.1), food processing residues (no.5 of Figure 2.1), and dung (no. 7 of Figure 2.1). Residues from the forest sector consist of forest residues generated in silvicultural management and round wood extraction (no.4 of Figure 2.1), and by-products from wood processing (no.3 of Figure 2.1). Two types of secondary residues generated in bioenergy feedstock processing are considered: bagasse and stillage in the sugarcane, rice husks, industry.
Residues from end use consist of non-food organic waste such as paper and other wood products, kitchen waste, faeces and urine. As was illustrated in figure 2.1, residues can be used for several purposes other than bioenergy.

The predominant approach in assessing the technical residue potential is to combine statistics / projections on food and fiber production with residue multipliers, i.e., factors that account for the amount of residues that is generated per unit primary product delivered. Recoverability factors are then used to estimate the practical residue potential. The amount of residues generated per unit primary product delivered is set constant over the scenario period, and without differentiation between regions.

[5] When considering the yield assumed in the reviewed studies, it should be noticed that some studies assumed HHV and others LHV, see Appendix C.

Table 4.4: Approaches in estimating residue generation and availability for energy in the reviewed studies, and basis for assumptions.

	Agriculture	Forestry	Basis for assumptions
WEC 94	Not specified		Based on expert judgement and per capita figures
GEP	Assumption, share of total supply		0-20 and 0-33 percentage of total biomass from residues in 2050 and 2100 respectively. Refer to LESS-BI
SEI/Greenpeace	Assumption, absolute contribution		Gradual phase-in of residue energy corresponding to 25% of residues estimated to be recoverable today. No own assessment, ref. to Hall (1992)
AGLU	Economic cost	Not considered	Crop residues are available at a specified cost that increases linearly up to full residue harvest level
SWISHER	Not specified		Based on literature from Hall
USEPA	Not considered		
SØRENSEN	Residue- and recoverability factors combined with production calculation		Share factors applied differ among regions for share of residues, recoverability applied for all regions. Not specified the basis.
HALL	Residue- and recoverability factors combined with production statistics		Identical factors applied for all regions over the whole scenario period. Contemporary global average factors in the food sector. For the forest sector, factors are based on U.S. forest sector of late 1970s.
RIGES	See HALL		See HALL
LESS-BI	See HALL		See HALL
LESS-BI / IMAGE	Assumption, absolute contribution		Adopts assumptions about residue availability made in LESS-BI
BATTJES	Not considered		
GLUE	Residue- and recoverability factors combined with production statistics		Not specified the basis
SHELL	Not specified		
SRES	Not specified		Not specified the basis
GBP2050	Residue- and recoverability factors combined with production calculation		Not specified th basis
DESSUS	Residue- and recoverability factors combined with production statistics		Based on per capita figures

Table 4.5 show the assumptions made in 5 studies in more detail. Figure 4.5 shows that the assumptions on residues do not vary largely among the studies. It is worthy to note that the all studies except GLUE refer (directly or indirectly) to HALL when assuming residue availability.

Table 4.5: Assumption on residue availability made in 5 studies.

Study	Type agricultural residues	Recoverability fraction	
		Forest	***Cr***
RIGES	Sugarcane, dung, cereals	50% forest 75% mill residues	25% of dung, 75% urban refuse, 25% cereals, 100% bagasse 66% of the tops and leaves
HALL	Sugarcane, dung, cereals	25% forest 75% mill residues	12.5 % dung, 25% cereals, 100% bagasse 25% of the tops and leaves
SWISHER		80% forest	Based on literature, not specified
LESS - BI	Sugarcane, dung, cereals	50% forest 75% mill residues	12.5 % dung, 75% urban refuse, 25% cereals, 100% bagasse 66% of the tops and leaves
GLUE	Sugarcane, dung, cereals, human faeces	10% paper scrap, 100% black liquor, 42% sawmill (DC), 7%% sawmill (IC), 75%scrap of timber and board	25% dung, 75% kitchen refuse, 25% human faeces, 25% cereal, 100% bagasse, 67% sugarcane tops and leaves

Traditional bioenergy

Traditional bioenergy –when considered– is treated differently among studies. In HALL, RIGES and LESS-BI, traditional fuelwood use is assumed to be phased out and replaced with modern fuels. Part of the wood resource base presently used for traditional uses is assumed to be available for production of modern biomass-based secondary energy carriers. In WEC94, GEP, SEI/Greenpeace, and AGLU traditional fuelwood is also assumed to be gradually phased out, but the wood resource base is not regarded a source for modern bioenergy.

The part of traditional bioenergy supplied by crop residues and dung is to a certain extent also assumed to be available for production of modern energy carriers. However no study explicitly treat this as a redirection of an existing biomass flow from traditional to modern bioenergy uses.

5. Results

In this chapter the results are presented on a global level, distinguished between industrialised and developing regions, and distinguished for the types of biomass[6]. Furthermore the differences between the results are discussed and linked to the different assumptions made and/or approaches used. For more detail on the results of each of the individual studies we refer to Appendix B.

5.1 The results of the assessments on biomass energy potentials

5.1.1 Global results

Figure 5.1 and Figure 5.2 present the results on the global bioenergy assessment according to the studies included in this report. Figure 5.1 shows the total contribution of biomass energy for each of the Resource Focus studies over time. Figure 5.2 shows the total contribution of Demand Driven studies. Figure 5.3 shows the relative contribution of biomass energy compared to total primary energy supply as assessed in 5 Demand Driven studies.

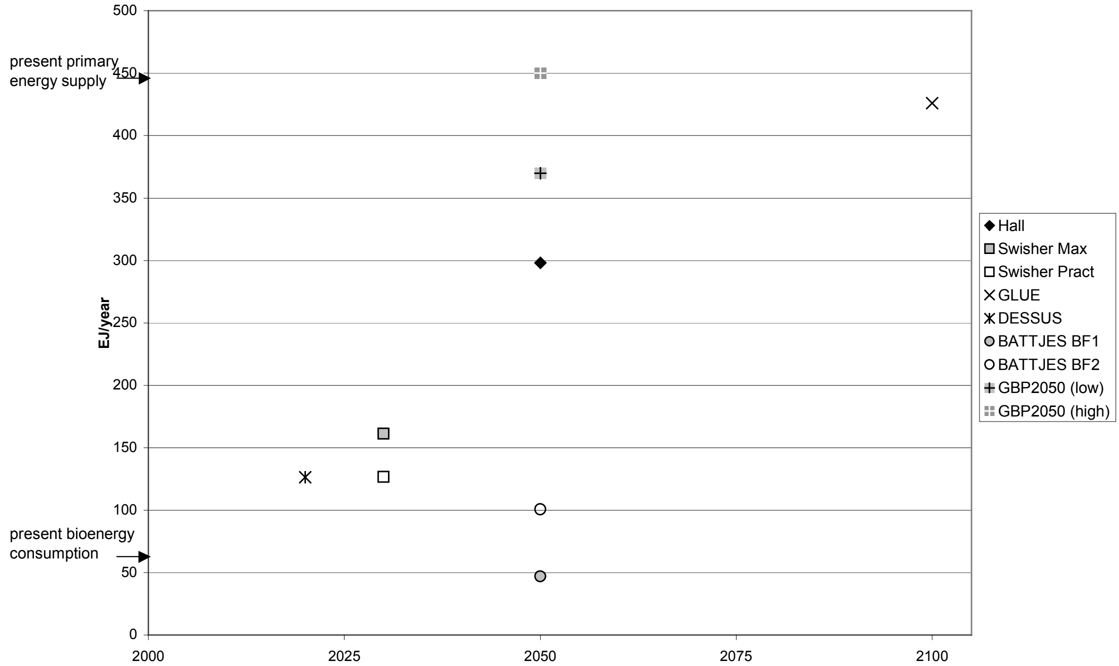

Figure 5.1: Contribution of biomass energy over time to 2100 according to Resource Focus studies included in this report

[6] Due to different expressions regarding the units of SØRENSEN and lack of information to convert them, these results were not yet included in this Chapter.

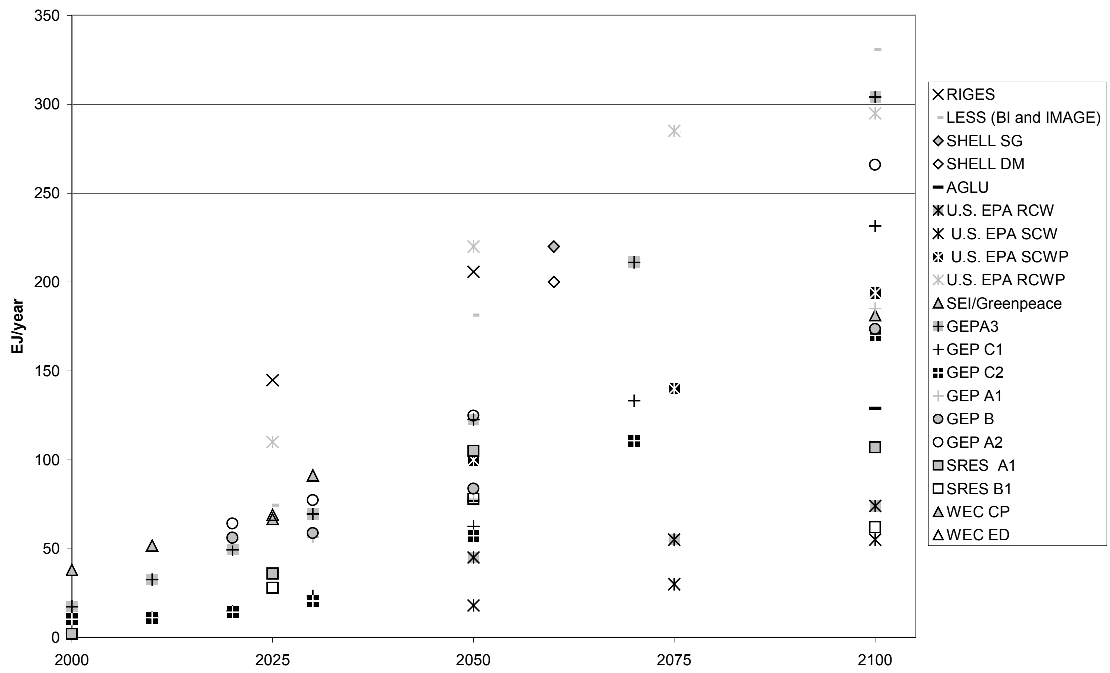

Figure 5.2: Contribution of biomass energy over time to 2100 according to Demand Driven studies included in this report

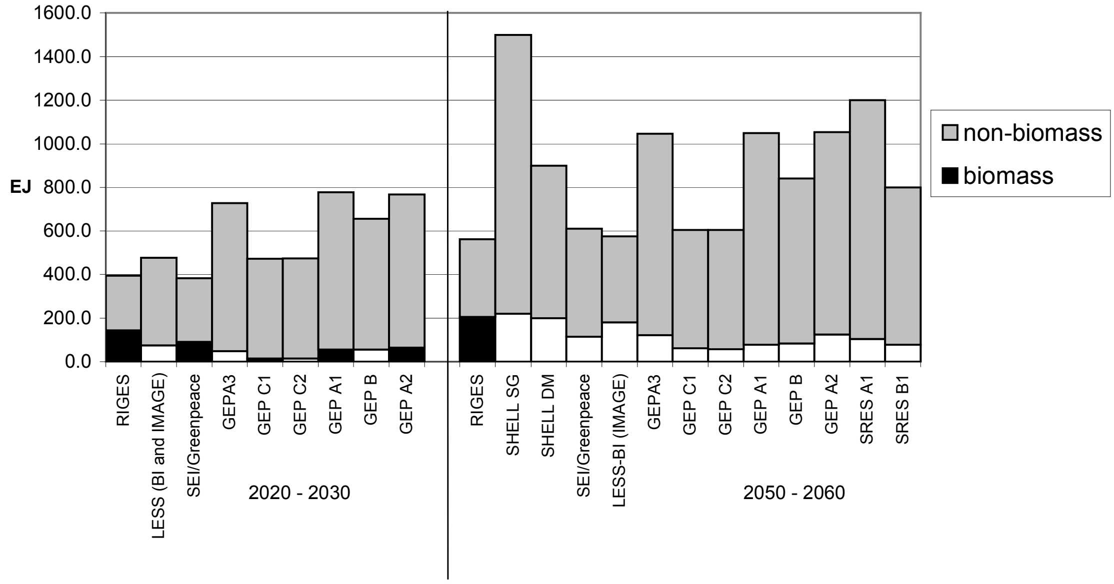

Figure 5.3: The reported potential of biomass energy as a share of total primary energy production up to 2060. Studies that did not give an estimate of total primary energy production were excluded from this figure.
NB: The presented studies are all classified as "Demand Driven"

Figure 5.1 and 5.2, show hat the results on global biomass energy potential vary widely among the studies included in this report. Looking at the year 2050, a lower limit is found of 18 EJ per year (U.S. EPA SCW scenario), which implies that the biomass energy consumption would decrease compared to the 55 EJ of present bioenergy consumption estimated by Hall (see Chapter 3). The highest estimate is GBP2050 (370 – 450 EJ in 2050).

Other high estimates are 300 EJ (HALL) 205 EJ/yr (RIGES) and 220 EJ/yr (U.S. EPA RCWP). These three lie between 50-70% of total present energy supply. The assessment of biomass energy potential increases in time for all studies.
When relating the biomass energy potentials to the assessed total energy consumption (see Figure 5.3.), it can be seen that the share of biomass energy of total primary energy production also varies widely. The lowest share is reported by GEP, being 3% for both Case C1 and C2 in 2020- 2030. In 2050 this share increased for both cases and resulted in a share of 10%. The contribution of biomass energy consumption in the RIGES study does not increase over time and remains relatively high at 36%, partly because of their low assumption on total primary energy supply. The LESS-BI study that is based on RIGES result in a share of 16% in 2020 – 2030, which increases to 31% in 2050.

5.1.2 The contribution of energy crops and residues

As was shown in Table 4.2 most studies include various types of bioenergy resources. All studies included the production of energy crops from dedicated plantations. Figure 5.4 presents the share of energy crops and residues in total primary bioenergy supply for three points in time.

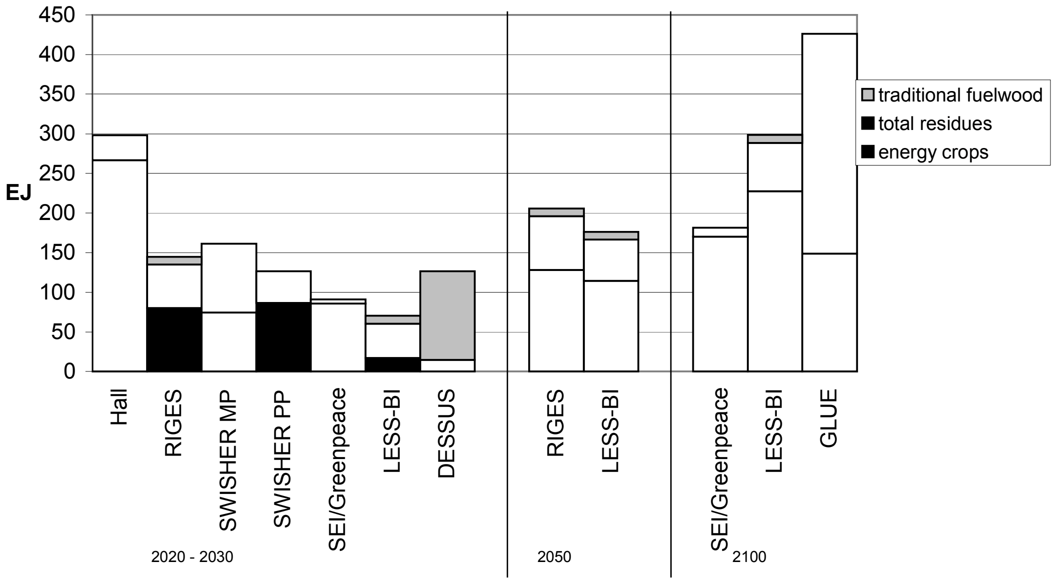

Figure 5.4: The share of energy crops and residues in total bioenergy supply. Studies that did not give a distinction between types of biomass were excluded from this figure[7].

Figure 5.4 shows that most studies report a higher potential for energy crops than for biomass residues. Especially Hall assumes a high contribution (almost 90%) of energy crops from dedicated plantations. However, SEI/Greenpeace assumes the highest share of energy crops (94%), which in absolute terms is 86 EJ for 2030 and 170 EJ for 2100. The lowest share is reported by DESSUS, at 12%. DESSUS included a relatively high share of traditional fuelwood. Remarkable furthermore is the share of energy crops of the LESS-BI assessment.

[7] SEI/Greenpeace did not specify the share of residues. We calculated this share based on figures on sugar cane productivity.

In 2030, this share is only 23%. However in time it increases from 64% in 2050 up to 76% in 2100. This is mainly caused by a high absolute increase of energy crops, rather than a decrease of residues in absolute terms. The energy crops were assumed to be able to increase rapidly since a doubling of the yield was assumed from 2025 up to 2100.

5.1.3 Regional differences

Since most studies aggregate over different regions, it is not possible to compare the regional contribution to the world biomass potential. Therefore a comparison has been made between industrialised and developing regions. This is shown in Figure 5.5 for three points in time.

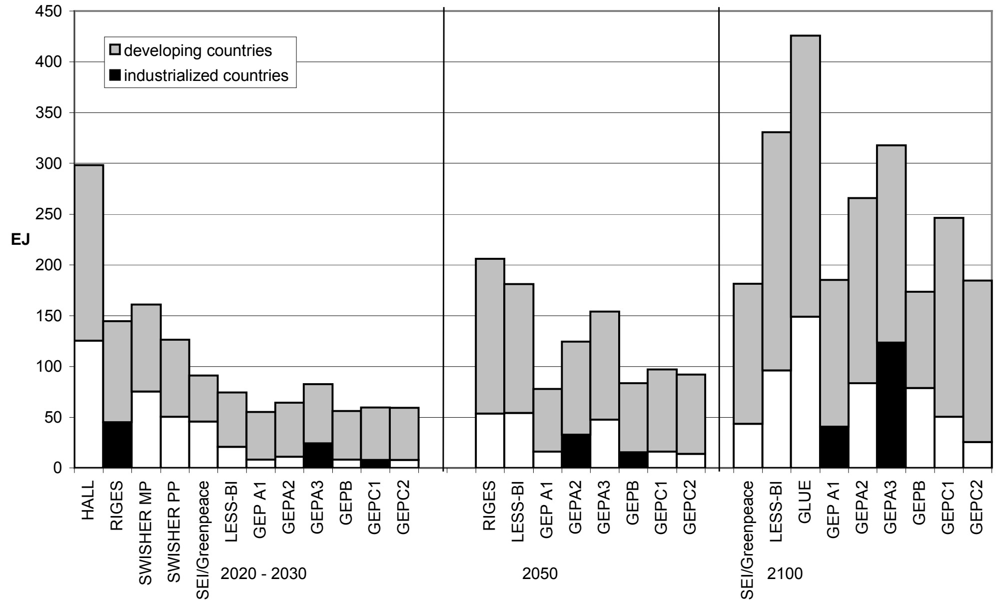

Figure 5.5: Reported biomass energy potential for developing and industrialised regions for three points in time. Studies that did not report any regional results were not included for this figure.

Figure 5.5 shows that the contribution of biomass energy is generally reported to be significantly larger in developing countries, than in the industrialised countries. The share of biomass energy potential in developing regions compared to the total reported potential lies for the time 2020 – 2030 between 50% (SEI/Greenpeace) and 87% for Case C1 and C2 from GEP. In 2100 the share lies between 69% (GEP A3) and 85% (GEP C2). Looking at developing regions in more detail (see Figure 5.6 for data of 2020-2030 and Appendix B), it shows that high potentials have been assessed both in Latin America, Africa and Asia. The high potential in Asia was due to high crop residue resources. Only HALL and SEI/Greenpeace estimated a large potential for energy crops in Asia. High potentials in Africa and Latin America are based on high estimates on land availability, with a high contribution from degraded land. In the industrialised region large potentials were assessed in the Former USSR and North America.

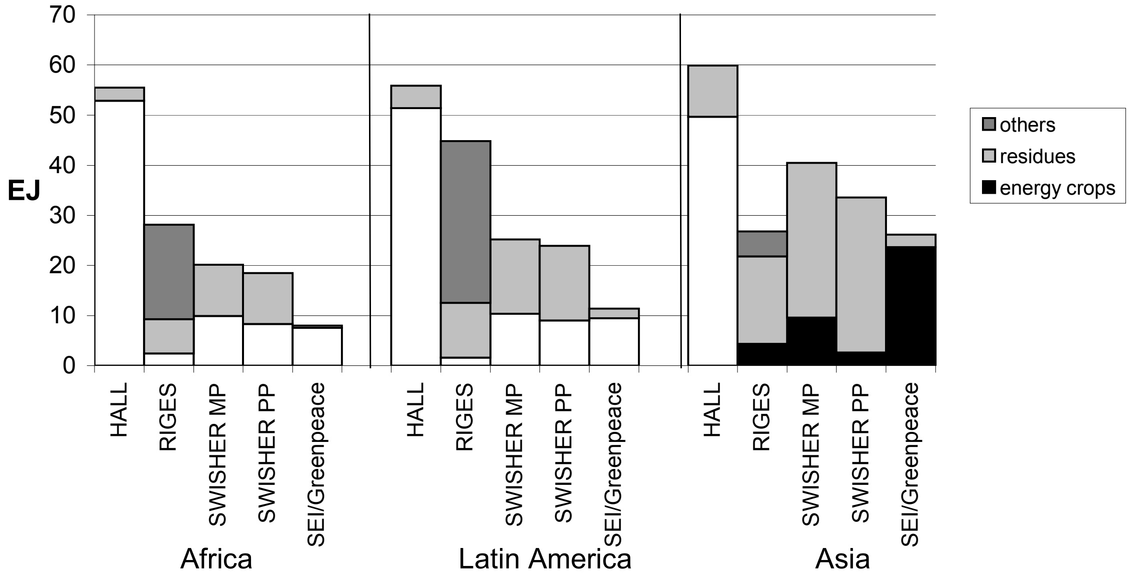

Figure 5.6: The total biomass energy production and the share of energy crops in three regions (time 2020 – 2030) according to three studies.

5.2 Explanation of differences in results

As mentioned in Chapter 4 the studies can generally be divided into energy demand driven approaches and resource based approaches. It cannot be stated that one approach results in higher potentials.

5.2.1 Demand driven

The demand driven approaches are usually driven by economic and demographic factors, such as GDP and population, except for WEC that used a different approach and is discussed at the end of this section. The population assumptions do not differ extremely among the studies, varying from 7 billion (SRES) to 13.6 in 2100 (U.S.EPA (SCW)). The GDP differs more (1.5 - 4.4%). This is partly the result of differentiating between developing and industrialised regions (e.g. LESS-BI). No direct relations were found between the differences in the results and the population and GDP assumptions, although these driving forces of course may have influenced the total energy demand. Illustrative is to compare SHELL, assuming an average per capita GDP in 2060 of US$ 17000 and a population of 10 billion , with RIGES, that has relatively comparable assumptions, GDP per capita US$ 13636 and population of 9.5 billion. In spite of this SHELL estimates of 1200 EJ, RIGES results in a global primary energy supply of 561 EJ. The linkages between the assessed *biomass* energy production and the economic and demographic driving forces are generally weak. Non of the demand driven studies related GDP and population directly to biomass energy. The only relation was indirect via the total energy demand. The total share of biomass depended on technology development assumptions and GHG abatement policies.

Technology development and environmental policies if assumed in the scenario, may have a large impact. This is illustrated by the four U.S. EPA scenarios where two scenarios are included with CO2 abatement policies and result in a higher biomass energy potential. This might also be said regarding the SEI/Greenpeace scenario. However within this scenario the technology development of other non-fossil options are assumed to increase rapidly, so biomass energy has to compete with wind and solar energy in this scenario.

WEC applied a totally different approach compared to the others. WEC used the present biomass energy consumption as a basis for the future biomass energy contribution. The types of biomass energy were categorised by modern and traditional biomass. The total amount of modern biomass was expected to expand 2-3 times within the next 30 years in industrialised countries for the “Current Policy” scenario. The traditional biomass energy use in developing countries is maintained. It was not made clear what estimation was used as the present biomass energy consumption. This makes it difficult to compare WEC with the other Demand Driven studies.

5.2.2 The explanation of the results of Resource Focussed studies

In this section we concentrate on the Resource Focused studies that have extreme results for 2020 - 2050. An overview of these extreme results is shown in Table 5.1.

Table 5.1 Extreme results of some resource focus studies included in this report.

	Total	Energy crops	residues		Animal waste	MSW
			Agricultural residues	Forest residues		
GBP2050 (high)	450	205	27	110	54	54
BATTJES	47	47				
HALL	298	267	13	14	5	
DESSUS	127	15	26 (incl. Animal)	86		
SWISHER (MAX)	161	75	87			

Comparing the extreme results of the Resource Focused studies (Table 5.1), a few results are notable. First it is noted that HALL and GBP2050 assessed a high potential of energy crops and BATTJES and DESSUS assessed a low potential of energy crop. The difference in the assessed potential of animal waste of HALL and GBP2050 is also notable. Furthermore GBP2050 and DESSUS include wood from forest as a type of biomass (GBP2050 based its assessment on DESSUS). This wood contributes to a large part of the total bioenergy potential for both studies, as part of forest residues.

Below the notable results of energy crops and residues are discussed separately for the five Resource Focussed studies.

Energy crops

HALL and GBP2050 estimated a large potential of energy crops, compared to BATTJES, DESSUS and SWISHER. Both HALL and GBP2050 assume large amount of areas available for energy crop production, however the areas have different origins. GBP2050 assumed energy crops to grow on grassland. The yields are estimated by using a crop growth model that includes agricultural soil quality, climate, water availability and the crop produced. The average global unweighted yield was assessed at around 100 GJ/ha/yr. The total amount of land required for the energy crop production was not possible to calculate since the exact amount of grassland per region was not given. We only had figures of the yield per region. However when the energy crop production is divided by the unweighted average yield, an area of around 1600 Mha could be found. This is in the same order of magnitude as the amount of the present cropland area (1400 Mha, [Hall, Rosillo-Calle et al. 1993]). HALL assumed in his study that 10% of land now in forest/woodlands + cropland + permanent pasture can be used for energy crops in 2050.

This is some 372 Mha. in industrialised countries and 518 Mha. in developing countries (total 890 Mha) In his assessment he discussed that this amount of land is lower than the difference between the land suitable for cropland and land required for cropland in 2025. Furthermore he discussed that the developing countries have a total of 426 Mha suitable for reforestation. HALL assumed high yields on the total area, at 300 GJ/ha/yr., which is three times the unweighted average yield estimated by GBP2050. Remarkable in this case is the area requirement of SWISHER. SWISHER used a similar approach to HALL. In this study it was also assumed that 10% of land now in forest/woodlands + cropland in industrialised countries and 10% of land now in forest + cropland + permanent pasture for developing countries could be available for energy crops. It was mentioned that this results in 500 Mha of land, 390 Mha less compared to HALL. This may be caused by not including pasture in industrialised countries and not including woodlands in developing countries. Furthermore SWISHER assumed a lower yield, i.e. 150 GJ/ha/yr in industrialised countries and 75 GJ/ha/yr at developing countries. In total, this results in a lower energy crop potential compared to HALL.

DESSUS used an approach completely different from the others. DESSUS related the availability of land for energy crops to the number of inhabitants per hectare cultivated land. The maximum ratio “r” of usable land on cultivated land has been taken as r = 10% - d/100 where d is the density of population by cultivated area. The assumed productivity by DESSUS was on average 170 GJ/ha/yr for short rotation crops, which is higher then SWISHER and GBP2050 and on average 600 GJ/ha/yr for sugar cane. By restricting the energy crops to cultivated land with a low population density, the total amount of area is low compared to the other studies (the total area was not given). The assumed ratio sugarcane vs short rotation crops was not made clear.

In the most conservative scenario of BATTJES it was assumed that energy crops could only grow on set aside land due to increased food production. This was only the case in industrialised regions, Latin America and few areas in China. The yield was estimated using a crop growth model in IMAGE 2.0. This depends on many aspects, among them the land allocation of the crops. However the yields assumed in [Leemans, van Amstel et al. 1996] where they used IMAGE 2.1 may be illustrative. In this study, yields were on global average 255 GJ/ha/yr, which is high compared to SWISHER, DESSUS and GBP2050, however still lower then HALL.

Residues

Concerning residues, it is notable that for forest residues two types of residues can be distinguished. The first type is called wood energy (GBP2050 and DESSUS). In this category the total renewable part of all existing forest is taken into account. The other category limits its residues to the present and future round wood production (HALL, SWISHER). These categories are discussed separately.

Both GBP2050 and DESSUS assumed that the renewable part of existing forests like direct wood logs, wood briquettes and pellets, charcoal or wood gas burning, could be used for energy. DESSUS made a distinction between commercial and non-commercial wood, GBP2050 made no distinction. The studies used different yield assumption for the forests, however same recoverability fractions were used.

It was assumed that only a share of the renewable part of the wood that is not in competition with raw materials (wood pulp timber etc.) (which varies between 50% for the industrialised countries regions and 70% for developing regions) is available for energy purposes. The accessibility varies between 80% in European countries to 25% in Latin America.

SWISHER and HALL restricted their forest residue potential to the residues that results from round wood harvest and round wood production. It was stated that not all residues could be utilised for energy purposes as was expressed by the recoverability fraction. It was assumed that some crop and logging residues should be left at the site to help ensure the sustainable production of the primary biomass product. Furthermore, some recoverable residues would be better used for other purposes. Moreover, it will not be practical or cost-effective to recover all residues. The assumptions on availability of forest residues of SWISHER were higher compared to HALL. HALL assumed a recoverability of 75% of mill residues and 25% of forest residues. SWISHER did not specify the type of forest residues, but assumed a recoverability of 80%.

Some considerations on recoverability were also made for animal residues. That is the reason why HALL assumed a lower potential for animal residues compared to GBP2050. HALL assumed that only 12.5% of the total amount of dung could be available for energy production. This recoverability fraction is lower than for agricultural and forest residues, because of the difficulties of recovering dung from grazing livestock. GBP2050 did not include this kind of recoverability factor and assumed a 100% availability of animal waste. When considering only 12.5 of the total amount of GBP2050, the figures from GBP2050 (7 EJ/yr) and HALL (5 EJ/yr) are relatively close. SWISHER assumed large potential of residues compared to HALL and GBP2050. For forest this was explained above, the assumptions on agricultural residues were not specified by SWISHER. This was also the case for GBP2050. GBP2050 used similar approaches concerning agricultural residues, however since GBP2050 did not specify the fractions on availability, it was not possible to compare them in more detail.

5.2.3 Mixture of Resource Focus and Demand Driven

In Figure 4.1 both approaches are presented as being totally demand driven or resource focus or a mixture of both approaches. RIGES includes both resource and demand constraints. Its resource-based constraints are derived for the Resource Focus study of HALL. The total energy demand was derived from an existing IPCC scenario and was satisfied to a certain extend by other renewable energy sources. As a result of this, it was not necessary to use the total resources as determined by HALL.

6. Discussion

In the previous sections the methodologies and results of various studies were described. In this section we discuss the main assumptions and relate them to other, not biomass energy related literature. We focus on the yield, land availability, residues and the required establishment rate of energy plantations.

Assumptions on the yield
Some studies, (LESS-BI, GEP "high yield", SEI/Greenpeace "double yield") have high assumptions on feasible productivity of energy plantations. Only SØRENSEN, LESS-IMAGE and BATTJES[8] used regional yield distribution. SWISHER and RIGES differentiated between industrialised and developing regions, on the basis of different management factors (RIGES furthermore includes natural conditions when assessing productivity).

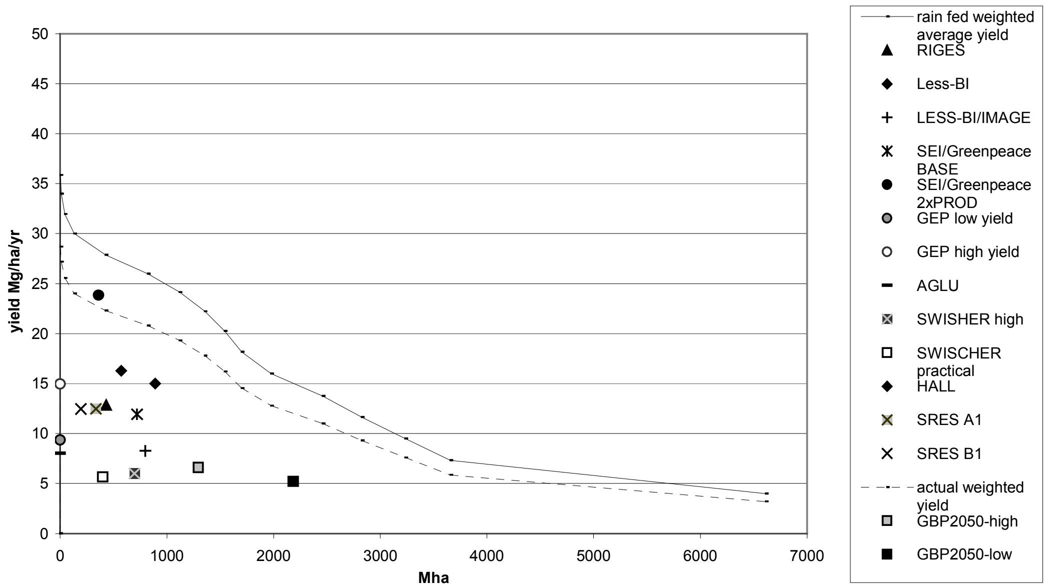

Figure 6.1: Yield supply curve for woody biomass on global level. Cropland and forestland are EXCLUDED. Data are taken from the Integrated Assessment Model IMAGE. Data from reviewed studies are average over region as well as over time.

Figure 6.1 shows the average global yield of woody biomass for non-agricultural and non-forest areas, as obtained by using IMAGE 2.1 data. The upper line represents the "rain fed" yield supply curve. This means that each point on this line represents the average rain-fed yield that can be obtained by using a certain number of hectares of the best available soil. The lower line represents the "actual" yield supply curve. This has been estimated by assuming that actual yield is about a factor 0.8 lower than rain-fed yield. This is about the average figure that is normally used in IMAGE (based on calibration results) to come from "rain-fed" to "actual" yield [Alcamo 1998]. The individual dots are the average yield assumptions of the reviewed studies.

[8] LESS-IMAGE and BATTJES used the integrated assessment model IMAGE

The highest assumption in Figure 6.1 is from the SEI/Greenpeace high productivity case. However, this assumption was used for a post-scenario feasibility check and did not directly contribute to the results. Figure 6.1 shows that all assumptions lie below the rain-fed supply curve and also below the actual yield curve (except for the SEI/Greenpeace high productivity case). This means that these yield estimations are comparable to the figures used in the IMAGE model.

Assumptions on land availability
The availability of land in most studies has a relative weak basis. Estimates of land availability for biomass energy plantations generally focus on surplus cropland in industrialised countries and degraded land in developing countries. Availability of the latter category for bioenergy plantations, is however seldom investigated in detail, and mostly based on literature. When comparing the total amount of land requirement from the reviewed studies (between 426 and 2185 Mha in 2050) with literature on forest based climate change abatement strategies land assumptions (see Appendix D. and Table 6.1), it can be seen that only GBP2050 require larger amounts of land than seemed to be available. However, part of this land was to come from present pasture land. The only study that explicitly mentions the amount of degraded land used for energy plantations is HALL. HALL assumes that out of the 758 Mha of degraded land as mentioned by Grainger (1988), 426 Mha will be used for energy crops. US-EPA RCWP assumes an amount of land available for reforestation of 380 Mha. These figure are both below most estimates from Table 6.1; only two sources mention a lower amount of degraded land available for reforestation.

Table 6.1: Selection of studies of land availability for forest-based climate change mitigation strategies. Adapted from (Berndes 2000)

	Potential area for forestation strategies (Mha)
(Grainger 1988)	758
(Grainger 1990) referred to in (Grainger 1991)	621
(Houghton, et al. 1991)	356-1079
(Houghton 1990)	865
(Bekkering 1992)	553
(Nilsson & Schopfhauser 1995)	345
(Trexler & Haugen 1995)	545
(Myers 1989)	300

Degraded land usually does not refer to wasteland deserted by humans, but to land that has lost productivity due to continuing improper land use. It is disputable what part of degraded lands is available and whether similar productivities as on croplands are possible, as has been assumed e.g. by HALL. In order to reach realistic estimates of the bioenergy potential of tropical degraded land, more detailed info is needed. The cost and benefits of different rehabilitation techniques have to be weighted against each other in the context of current and future local objectives and priorities. Furthermore the yield on degraded land need to be studies in detail.

Residues
All studies have relatively rough assessments of residue availability. Some studies do not make their own assessment of the residue potential. Instead the contribution from residues is set to a certain level, with reference to other estimates of the residue potential (see table 4.4).

This approach introduces a mixing of different scenarios of the future that may cause inconsistencies. The studies do not explicitly relate the amounts of residues assumed to be available for energy to the actual residue flows in the food and forest sectors, but assumed “no constraints on the availability”. HALL, RIGES and LESS-BI based the availability on production figures, product to residue ratios and recoverability factors. However these studies did not directly include possible competing uses of residues.. Therefore, it is difficult to evaluate whether this approach jeopardise the credibility of the studies.

It is interesting to notice that some studies did not study the availability of residues on a resource basis, Furthermore when considering residues, no study includes the drawback of loss of organic matter in the soil by removing large amount of residues. Both aspects may cause a lower availability of residues. In some cases, this competing uses may have implicitly been included within the recoverability factor.

Establishment rate

The required expansion rate of the bioenergy plantation area is noteworthy. For example, to reach 500 million hectares in 2025 (AGLU) the average annual global expansion will have to be around 20 million hectares per year. This is above 7 times as high as the present total establishment rate of round wood plantations (both industrial and non-industrial) in developing countries, being approximately 3 million hectares (FAO 1999). A sharp increase of this establishment rate is required for tropical developing countries to become the major supplier of plantation-grown bioenergy in the coming decades.
The problem with the rate of establishment has also been mentioned by Williams in the LESS-BI study. This is why the share of energy crops is increasing slowly.

7. Conclusion and recommendation

Looking at the results and the approaches from the studies on the global future contribution of bioenergy, the following conclusions can be drawn.

Results
The results of assessments of biomass energy potential vary largely.
HALL was the resource focussed study that has (partly) been used in many other studies. The estimated potential was 300 EJ, which did not have a specific time reference. The resource focussed studies that estimate a bioenergy potential for 2020-2030 lie between 66 (WEC CP) and 161 EJ (SWISHER MAX). In 2050 they lie between 370 EJ/yr (GBP2050 low) and 450 EJ/yr (GBP2050 high). The latter almost equals the present total primary energy supply. Only one study (GLUE) gives a resource focussed estimate for 2100 at 426 EJ/yr.
The range of demand driven studies up to 2050 lies between 18 EJ/yr (US EPA in 2050) and 205 EJ/yr (RIGES in 2050). In 2100 the results from demand driven studies vary widely between 55 EJ/yr (US EPA) and 331 EJ/yr (LESS-BI).

HALL and GBP2050 estimated a large potential of energy crops, compared to BATTJES, DESSUS and SWISHER. Both HALL and GBP2050 assume large amount of areas available for energy crops production, however the areas have different origins. HALL assumed in his study that 10% of land now in forest/woodlands + cropland + permanent pasture can be used for energy crops in 2050 (total 890 Mha). GBP2050 assumed energy crops to grow on grassland at an area of around 1600 Mha. HALL assumed high yields on the total area, at 300 GJ/ha/yr., which is three times the unweighted average yield estimated by GBP2050.
Concerning residues, it is notable that for forest residues two types of residues can be distinguished. The first type is called wood energy (GBP2050 and DESSUS). In this category the total renewable part of all existing forest is taken into account. The other category limits its residues to the present and future round wood production (HALL, SWISHER). SWISHER and HALL restricted their forest residue potential to the residues that results from round wood harvest and round wood production. It was stated that not all residues could be utilised for energy purposes as was expressed by the recoverability fraction (HALL assumed a recoverability of 75% of mill residues and 25% of forest residues. SWISHER did not specify the type of forest residues, but assumed a recoverability of 80%). It was assumed that some crop and logging residues should be left at the site to help ensure the sustainable production of the primary biomass product. Furthermore, some recoverable residues would be better used for other purposes. Moreover, it will not be practical or cost-effective to recover all residues. The first category results by definition in larger potential estimations.

The assumptions on availability of forest residues of SWISHER were higher compared to HALL. Some considerations on recoverability were also made for animal residues (12.5%). That is the reason why HALL assumed a lower potential for animal residues compared to GBP2050.

The variation in the results for demand driven studies is mainly caused by different assumptions on technology development and environmental policy assumed. As the four cases of GEP show, the A3 scenario with high growth and fast technology development results in contribution of biomass energy, which is even than in the case that includes ecologically driven policy.

Approach
Many studies use comparable approaches based on the same background study. Regarding the approaches of the reviewed studies, it is concluded that many resource focussed assessments are based on assumptions made by HALL. Especially the assumptions regarding residues are not based on field experiments but on literature (Hall). Furthermore, it is noteworthy that many studies do not make bottom up assumptions, but assess the total amount of biomass energy and check the feasibility of the results afterwards (GEP, SEI/Greenpeace). This type of post scenario feasibility checks is seldom based on firm data.
It can be concluded that with the present approaches, analysts *avoid* rather than *analyse* the competition for land between different land uses and residue uses.

Recommendation
The studies considered in this report can largely be considered as first generation studies on the global potential for biomass energy. Second generation studies could be improved on the following points.

- Data on present consumption are lacking. For a good assessment of the potentials of biomass energy, it is recommended to start with a better understanding of the present consumption. This causes insight in the amount available, the competition with other purposes and can be a basis for the main assumptions regarding future product to crop ratio and yield.
- Almost no study takes the competition with food and other biomass purposes into account in an integrated way. However this should be included because may be an important constraint for biomass energy as was shown in the LESS-IMAGE study. By ignoring the competition, the assessments may be overestimated.
- Much improvement if possible with respect to the assessment of yields of energy crops, including better regional differentiation for various soil types, climatological conditions and management factors. This could make the potentials more realistic.
- Related to the recommendation above, the economics of biomass energy need to be included. This can only be done when good insight is gained in the competition between land and demand for residues for non-energetic purposes. Insight in the costs of biomass energy gives insight in the magnitude that might penetrate the market.

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Appendices of the GRAIN report : A review of assessments on the future global contribution of biomass energy

Page

Appendix A: Acronyms and full references of reviewed studies

Acronym	Main reference
WEC 94	World Energy Council, 1994. *New Renewable Energy Resources*. Kogan Page Ltd.
GEP	Nakicenovic, N., A. Grübler & A. McDonald, 1998. *Global energy perspectives*. International Institute for Applied Systems Analysis/World Energy Council. Cambridge University Press
SEI/Greenpeace	Lazarus, M., L. Greber, J. Hall, C. Bartels, S. Bernow, E. Hansen, P. Raskin & D. von Hippel, 1993. *Towards a Fossil Free Energy Future*. Stockholm Environmental Institute –Boston Center
AGLU	Edmonds, J.A., M.A.Wise, R.D.Sands, R.A.Brown, H. Kheshgi, Agriculture, land use, and commercial biomass energy: A preliminary integrated analysis of the potential role of biomass energy for reducing future greenhouse related emissions, Pacific Northwest National Laboratory, Report prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, 1996
SWISHER	Shwisher, J. and D. Wilson, Renewable energy potentials, In: Energy Vol. 18 No 5. Pp 437-459, 1993
U.S. EPA	Lashof, D. A. & D. A. Tirpak (Eds.), 1990. *Policy options for stabilizing global climate*. Hemisphere Publishing Corporation, New York, Washington, Philadelphia, London
SØRENSEN	Sørensen, B., 1999. *Long-term scenarios for global energy demand and supply: Four global greenhouse mitigation scenarios*. Roskilde University, Institute 2, Energy & Environment Group, Denmark IMFUFA text 359.
HALL	Hall, D. O., F. Rosillo-Calle, R. H. Williams & J. Woods, 1993. *Biomass for Energy: Supply Prospects*. In: Renewable Energy: Sources for Fuels and Electricity. T. B. Johansson, H. Kelly, A. K. N. Reddy & R. H. Williams. Island Press, Washington, D.C.**:** 593-651.
RIGES	Johansson, T. B., H. Kelly, A. K. N. Reddy & R. H. Williams, 1993. *Renewable Fuels and Electricity for a Growing World Economy –Defining and Achieving the Potential*. In: Renewable Energy: Sources for Fuels and Electricity. T. B. Johansson, H. Kelly, A. K. N. Reddy & R. H. Williams. Island Press, Washington, D.C.**:**
LESS-BI	Williams, R. H., 1995. *Variants of a low CO2-emitting energy supply system (LESS) for the world: Prepared for the IPCC Second Assessment Report Working Group IIa, Energy Supply Mitigation Options*. Pacific Northwest Laboratories PNL-10851
LESS-BI / IMAGE	Leemans, R., A. van Amstel, C. Battjes, E. Kreileman & S. Toet, 1996. "The land cover and carbon cycle consequences of large-scale utilizations of biomass as an energy source". *Global Environmental Change* **6**(4): 335-357.
BATTJES / IMAGE 2.0	Battjes, J. J., 1994. *Global options for biofuels from plantations according to IMAGE simulations*. Interfacultaire Vakgroep Energie en Milieukunde (IVEM), Rijksuniversiteit Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands IVEM-Studentenrapport No. 77.
GLUE	Fujino, J., K. Yamaji & H. Yamamoto, 1999. "Biomass-balance table for evaluating bioenergy resources". *Applied Energy* **63**75-89.
	Yamamoto, H., K. Yamaji & J. Fujino, 1999. "Evaluation of bioenergy resources with a global land use and energy model formulated with SD technique". *Applied Energy* **63**: 101-113.
GBP2050	Fisher, G. and L. Schrattenholzer, Global bioenergy potential through 2050, In: Sustainable Energy: New Challenges for Agriculture and Implications for Land Use, Eds: E. van Ierland, A. Oude Lansink, E. Schieman, Wageningen, 2000
DESSUS	Dessus, B., B. Dervin and F. Pharabod, “World potential of renewable energies – Actually accessible in the nineties and environmental impacts analysis”; La Houille Blanche, Paris, 1992
SHELL	Shell International, The evolution of the world’s energy system 1860 – 2060, Shell Centre, London, 1995
SRES	B1 scenario: De Vries, B., J. Bollen, L. Bouwman, M. den Elzen, M. Janssen and E. Kreileman Greenhouse Gas Emissions in an equity-, environment-, and service-oriented world: An IMAGE-based scenario for the next century. Technological Forecasting and Social Change 63 (in press), 2000.
	A1 scenario: IPCC Special Report on Emission Scenarios. Cambridge University Press, 2000

B1. Name: Sørensen

(Sørensen 1999)

Timeframe: 2050

Geographical aggregation: world, aggregated into 6 regions:

1. United States, Canada
2. Western Europe, Japan, Australia
3. Eastern Europe, Ex-Soviet, Middle East
4. Latin America, SE Asian "tigers"
5. China, India, rest of Asia
6. Africa

Background: Sørensen studied the long term global energy demand and supply by using four greenhouse gas mitigation scenarios. The project was performed for the Danish Energy Agency under its Energy Research Programme in the area of "Energy and Society". Sørensen used a Geographic Information System with grid cells of 0.5° x 0.5° for his scenario simulation.

Used Driving Forces/Scenario:

Of the four scenarios used in the study, the renewable energy scenario included explicitly the use of biomass energy. Biomass energy use was divided into two categories; decentralised and centralised biomass energy use. According to Sørensen biomass used in a decentralised mode means using the land areas already devoted to agriculture and forestry. Centralised biomass is subsequently defined as biomass cultivated as dedicated energy crops or energy forest.

Population: The population assumptions within the scenarios were based on the United nations population study which estimates the population at year 2050 in its middle variant at 9.4 billion people. On a global basis the share of urban population is assumed to be 74%, ranging from 68% in Sub Saharan, Africa region unto 90% in North America.

Energy: The average 1994-2030 per capita growth factor for the demand scenario end-use energy is 2.7. (A de-coupling is assumed which implies that the GNP per capita growth to year 2050 will be substantially larger than the factor 2.7).

Additional: Within his scenario, Sørensen assumed a demand for food varying between the six regions. The actual 2050 scenario food energy corresponds to full satisfaction of needs excepts for Africa. The ratio between vegetable food and animal food vary among regions, although the variation is less than today. A move towards a more healthy diet in the currently most meat-intensive parts of the world is considered.

Table B1.1 presents the population figures and the energy delivered the end-user in 2050 scenario for food based on animals and food based on grain & vegetables.

Table B1.1: Population and energy delivered the end-user in 2050 scenario for food based on animals and food based on grain & vegetables

	1. United Sates, Canada	2. W-Europe, Japan, Australia	3. E-Europe, Ex-Soviet, Mid. East	4. Latin America, SE Asian "tigers"	5. China, rest of Asia	6. Africa	Average/ total	Unit
Food based	30	30	30	25	25	20	23	%
on animals	45	45	45	37	37	25	36	W/cap
	17	24	47	52	148	51	339	GW
Food based	70	70	70	75	75	80	77	%
on grain &	119	119	119	128	128	114	123	W/cap
vegetable	45	63	124	177	506	232	1148	GW
Population	379	528	1040	1380	3960	2040	9340	millions

Types of biomass included

Sørensen assessed the future possible biomass consumption within his scenario by distinguishing three types of decentralised biomass, related to the food production and two types of centralised biomass on cropland and rangeland areas.

Energy Crops: From the centralised types of biomass two energy crop routes were included; biomass from energy crops on cropland and from energy crops on rangeland.

Yield: As an indicator of the potential productivity on a grid based level (0.5° X 0.5° grid), the net primary production (NPP) data were calculated by using the Terrestrial Ecosystem (TEM). The TEM is a processed-based ecosystem simulation model that uses spatially referenced information on climate, elevation, soils, vegetation and water availability to make monthly estimates of among other things NPP. The NPP data from TEM are expressed in grams of carbon per square meter per year[1]. The TEM database is for mature ecosystem. This means that water and nutrient limitation would be less severe compared to annual crops. As a proxy for cultivation yields provided that one assumes better farming techniques used by 2050 and assumes that irrigation and chemical fertilizers are used when necessary. The model does not specify which crops will be cultivated at a given location, but simply assumes productivity consistent with growing crops suited for the conditions.

Available area: Within the centralised scenario it was assumed that 50% of the rangeland areas were regarded as potentially exploitable for energy crops. On cropland it was assumed that 10% might be set aside for energy crops in areas of generous resources such as Western Europe and the Americas. This can be done because it was assumed that food crop production increase to equal the production to mature ecosystem.

The total amount of biofuels from cropland and rangeland have been presented by respectively Eq B1.1 and Eq B1.2.

[1] It was mentioned that these NPP data could be translated into units of grams of dry matter per square meter per year by multiplying with a factor of 2.05[2,] and into units of watt-years per year per square meter by multiplying with a factor of 0.00133.

Biofuels from energy crops on cropland =
AF (cropland) x PP [W/m2] x AE x HF x UF (cropland energy crops) x FE   Eq B1.1

Biofuels from energy crops on rangeland =
AF (rangeland) x PP [W/m2] x HF x UF (rangeland energy crops) x IE (anim. prod)   Eq B1.2

In which:
AF = Area Fraction (grid based)
PP = potential production (grid based)
AE = agricultural efficiency factor (regional based)
HF = harvest fraction (regional based)
UF = utilisation factor (regional based)
FE = conversion efficiency (constant)
IE = efficiency transforming biomass into delivered products

Forest residues: The use of forest residues was included within the decentralised mode of the renewable energy scenario. This was based on the present forestland and the calculation made with the TEM model.

Primary/secondary Forest Residues: Only primary forest residues were included, secondary forest residues were not included.

Recoverable fraction of FR: For biofuels from forest management a collection fraction of 30% was used defined as percentage of the total harvested fraction of the forest biomass production.

The total amount of forest residues used for biomass energy has been presented by Eq B1.3.

Biofuels from forest management =
AF(forestland) x PP[W/m2] x HF x UF(fodder) x CF(forestry) x FE   Eq B1.3

Agricultural residues: The decentralised types of biomass were categorized in three types of biomass; biomass from vegetable food crops, manure (and biofuels from forest management). It was assumed that the land area used for food crops is the same in 2050 as now**.**
The potential food biomass production has also been calculated with net primary production data from TEM.

Recoverable fraction: The biofuels from vegetable food crops were assumed to depend on the vegetable food crop production multiplied by a collection fraction of 25% (and a conversion efficiency of 50%). For manure the collection was assumed to be 60%, this also includes other animal biomass like slaughter waste.

Eq B1.4 and Eq B1.5 present way the biofuels from agricultural residues are simulated.

Biofuels from vegetable food crops =
AF (cropland) x PP[W/m2] x AE x HF x UF(vegetable food) x CF(veg, waste) x FE   Eq B1.4

Biofuels from manure and other animal residues =
AF(cropland) x PP[W/m2] x AE x HF x UF (fodder) x (1-IE(anim. Prod.)) x CF (anim) x FE   EqB1.5

Table B1.2 presents the parameters used for cropland biomass production in 2050 scenario; the cropland agricultural efficiency (AE), the harvest fraction (HF) and the utilisation factor (UF).

Table B1.2: Parameters used for cropland biomass production in 2050 scenario

Region	AE (cropland)	HF	UF (veget. Food)	UF (fodder)	UF (energy Crops)
1. United Sates, Canada	1	0.4	0.4	0.5	0.1
2. W- Europe, Japan, Australia	1	0.4	0.4	0.5	0.1
3. E-Europe, Ex-Soviet, Mid. East	0.7	0.4	0.5	0.5	0
4. Latin America, SE Asian "tigers"	0.7	0.4	0.4	0.5	0.1
5. China, rest of Asia	0.7	0.4	0.7	0.3	0
6. Africa	0.7	0.4	0.8	0.2	0

Urban waste: The study did not include urban waste biomass to be used.

Conversion technologies included: It was stated that a number of fuels might be produced from biomass and residues, ranging from fuels for direct combustion, over biogas to liquid biofuels or gaseous fuels. Whether the biofuel production is by thermal or biological processes, the expected conversion efficiency (FE) is of the order of 50%.

Cost estimates: Sørensen did not include cost aspects within his scenario approach.

Results:

Table B1.3 presents the regional results of the centralised and decentralised use of biomass energy in the renewable energy scenario for 2050.

Table B1.3: Estimations of centralised and decentralised use of biomass energy in the renewable energy scenario for 2050 from Sørensen (1999)

Region	1. United Sates, Canada	2. W-Europe, Japan, Australia	3. E-Europe, Ex-Soviet, Mid. East	4. latin America, SE Asian "tigers"	5. China, rest of Asia	6. Africa	Total (GW)	EJ/yr
Total food balance	151	144	107	283	-23	-267	493	
Total biofuels used	250	190	300	640	327	192	1899	
Of which decentralised biofuels	250	166	236	640	295	192	1779	
Balance: total biofuels minus use for transportation	136	158	146	277	392	61	1170	

B2. Name: WEC
(WEC 1994)

Timeframe: 2020

Geographical aggregation: world, aggregated into 9 regions
1. North America
2. Western Europe
3. E Europe + NIS
4. Japan + Australia
5. Latin America
6. Mid. East + N Africa
7. Sub-Saharan Africa
8. Pacific + SE Asia
9. South Asia

Background: In 1994 the World Energy Council assessed the worldwide renewable energy resources and among them the biomass resources. The WEC stated that the future use of bioenergy is very difficult to predict. At best, informed guesses can be offered. Two contradictory trends were taken into account when estimating future biomass use.
1) There is a growing transition in developing countries, away from traditional biomass use to fossil fuels as biomass resources become more scare and populations urbanize.
2) The biomass consumption is likely to increase, for the three main reasons:
   - population growth in developing countries where the majority rely on biomass for their energy needs;
   - environmental pressure in industrialized countries;
   - new biomass energy technologies hat will increase efficiencies and reduce costs.

An approach for prognosticating the biomass use within each region was developed using expert consensus and was based on the population expansion and an anticipated development of the biomass use per capita.

Used Driving Forces/Scenario:
Two scenarios have been employed. The “current Policies” (CP) scenario and the “Ecologically Driven” (ED) scenario. The CP scenario postulates that the present pace of biomass development is maintained and even expanded in response to currently identified trends. In this scenario in the industrialized countries, the traditional biomass use per capita is maintained while the use of modern biomass is expected to expand by a factor 2-3 times within the next 30 years. In the developing countries traditional use of biomass energy is reduced due to increased limitations on availability. As per capita level of new biomass may be well below what is needed for survival. For the second “Ecologically Driven” (ED) scenario is assumed that a major effort will be made to enhance the use of modern biomass.

In the industrialized world the traditional use per capita of biomass is reduced to approximately 70% of current levels in 30 years due to environmental concerns, and the use of modern biomass will be enhanced considerably. In developing countries it is assumed that the increased availability of technology and capital coming from the developed countries allow for a major increase of new biomass per capita. This in turn allows for a substantial decrease, estimated at 60%, in the traditional biomass use and its accompanying negative side effects both for the persons involved and the environment.

Population: The estimates for the world population growth per region included in the two scenarios by the WEC are presented in Table B2.2.

Table B2.2: estimates for the world population growth per region unto 2020 included in the two scenarios by the WEC

Populations (millions)	1990	2000	2010	2020
North America	276	292	309	326
Western Europe	454	465	477	489
E Europe + NIS	389	411	433	455
Japan + Australia	144	147	151	155
Latin America	448	537	626	716
Mid. East + N Africa	271	362	453	544
Sub-Saharan Africa	501	732	963	1195
Pacific + SE Asia	1663	1866	2069	2273
South Asia	1146	1410	1674	1938
Industrialized world	1263	1315	1370	1425
Developing world	4029	4907	5785	6666
World total	5292	6222	7155	8091

Types of biomass included

The WEC stated that the biomass resources suitable for energy production encompass a wide spectrum of materials. These ranges from fuelwood collected from farmlands and natural woodlands, through agricultural and forestry residues, food and timber processing residues, municipal solid waste (MSW) and sewage, to aquatic flora.

The WEC divided bioenergy into two categories loosely described as modern and traditional. Modern bioenergy includes:

- wood residues (industrial);
- bagasse (industrial);
- urban waste;
- biofuels (inc. biogas and energy crops).

The traditional biomass includes:

- fuelwood and charcoal for domestic use;
- straw including rice husks;
- other vegetation residues;
- animal waste.

The traditional biomass (fuel wood, crop residues and dung) that account for 60% of the total amount of renewable energy in 1990 are expected to account for over half the total even in 2020.

Energy Crops: The use of energy crop is included as part of the modern biomass energy.

Yield[2]: It was stated that the yield currently 3-7 Mg ha^{-1} yr^{-1}. Mainly due to increasing nutrient availability, doubling or even tripling of the productivity does not seem too farfetched according the WEC.

Available area[2]: WEC discussed the availability of land for their projections based on literature. For the developing world calculations show that there is ample room for providing the biomass energy assumed in the prognoses. However, it was stated that the investment capital is limited and must come from the industrialized countries.
For the industrialized world, higher productivity levels were assumed. It was stated that both the USA and the EU have at the present plans to make as much as 90 Mha each idle due to overproduction of agricultural products. If this area is used for energy production with a average yield of 10 Mg ha^{-1} yr^{-1}, more than twice the estimated modern biomass energy production in the industrialized countries could be produced (90 Mha x 10 Mg ha^{-1} yr^{-1} x (15 GJ/Mg) = 13.5 GJ).

Forest residues: The use of forest residues have not explicitly been taken into account.

Urban waste: The use of urban waste has not explicitly been taken into account.

Conversion technologies included: Biomass conversion technologies have been separated into three basic categories:

- direct combustion;
- thermochemical processes
- biochemical processes

However, they have not been included in the assessment.

Cost estimates[2]: Based on literature review, it was stated that the estimates of costs of delivered air dry biomass chips in a number of countries ranges from US$ 1.9 to 3.9 GJ (1987) and applies to both industrialized and developing countries. The cost of electricity production based on newly constructed biomass technologies in the USA is reported as 5-6 US cents/kWh (1989). For developing countries the energy supply costs for electricity were stated to be of the order of 1.4 US cents/kWh, and for Europe (Netherlands) the price may be as high as 8 – 10 US cents/kWh.

Results:

The estimations on future biomass energy consumption made by the WEC (1994) , are stated in Table B2.2.

[2] It should be noted that the assumptions on yield, available area and costs have been made at the end, aiming to discuss the feasibility of the projected potentials.

Table B2.2: Biomass energy consumption assessments in 2020 by WEC (1994) for two scenarios in Mtoe/yr (EJ/yr)

	1990		2020 CP		2020 ED	
	Traditional	Modern	Traditional	Modern	Traditional	Modern
North America	38	19	46 (1.96)	55 (2.34)	36 (1.53)	68 (2.90)
W Europe	20	10	20 (0.85)	24 (1.02)	15 (0.64)	34 (1.45)
E Europe + NIS	30	10	36 (1.53)	23 (0.98)	23 (0.98)	32 (1.36)
Japan + Australia	4	7	5 (0.21)	20 (0.85	3 (0.13)	23 (0.98)
Latin America	125	46	179 (7.63)	72 (3.07)	144 (6.14)	186 (7.93)
Mid East + N Africa	21	0	38 (1.62)	0 (0)	27 (1.15)	11 (0.47)
Sub Saharan Africa	141	5	299 (12.74)	12 (0.51)	239 (10.19)	48 (2.05)
Pacific + SE Asia	347	16	409 (17.43)	23 (0.98)	341 (14.53)	91 (3.88)
South Asia	204	8	291 (12.40)	14 (0.60)	232 (9.89)	68 (2.90)
Industrialized world	92	46	107 (4.56)	122 (5.20)	77 (3.28)	157 (6.69)
Developing world	838	75	1216 (51.83)	123 (5.16)	983 (41.90)	404 (17.2)
World Total	1051		1568 (66.75)		1621 (69.09)	

B3. Name: Swisher

(Swisher and Wilson 1993)

Timeframe: 2030

Geographical aggregation: world, 20 regions

1. Canada	2. USA
3. Mexico/Central America	4. Andean countries
5. Brazil	6. Southern Cone
7. Nordic countries	8. Western Europe
9. Eastern Europe	10. Former USSR
11. Japan	12. Australia/New Zealand
13. China	14. India
15. Four Tigers	16. ASEAN
17. Other Asia/Pacific	18. Middle East
19. North Africa	20. Sub-Saharan Africa

Background: In the special issue of the international journal 'Energy', by guest editor Naki enovi , the potential of biomass energy and renewable energy sources (mainly decentralized) had been assessed. The energy potential had been calculated by technology and by region, for both the "maximum potential" case and a more conservative, though still aggressive, "practical potential" case. The main of the study was to identify which biomass and renewable energy technologies are likely to be important globally, regionally, locally or not at all unto 2030.

Used Driving forces/scenario:

The estimation was done by using assumptions on available amount of biomass from energy crops and waste taken from literature. The assumptions on the conversion technology were based on expert judgements.

Types of biomass sources included

Two general categories were considered: wastes and energy plantations. Traditional uses of non-commercial biomass energy for fuelwood in developing countries were excluded.

Energy Crops: The use of energy crops had been taken into account, mainly based on existing literature. For the more conservative potential assessment (practical potential) data were used from Dessus (Dessus, Devin et al. 1991). For the maximum potential the approach on yield and available area is described below.

Yield: For industrialized countries data on yield were taken from David Hall (1991)[3]. It was assumed that the average yield is 150 GJ ha^{-1} yr^{-1}. In developing countries the same source mentioned a average yield of 75 GJ ha^{-1} yr^{-1}

[3] (Hall 1991)

Available area: For industrialized countries data on the available area were taken from David Hall (1991). It was assumed that 10% of the total cropland, forest and woodlands were available. For the USA and Nordic countries the land area values were increased based on case-studies. The available area in the developing countries was also taken from Hall (1991). It was assumed that 10% of the total crop, pasture and forest lands, resulting in 500 million ha.

Forest residues: Data on the recoverable amount of forest residues were taken from country-by-country estimations from David Hall (1991) the recoverable fraction for forestry wastes was assumed to be 80% on global average basis.

Agricultural residues: For the potential of agricultural residues, data were taken from David Hall (1991). Hall gave a country-by-country overview of the energy content of residues. Swisher and Wilson only mentioned a global average for animal waste of 25%.

Urban waste: The use of municipal waste and sewage was taken into account, however the approach was not described.

Conversion technologies included: It was assumed that the biomass could be converted to commercial fuels and electricity. It was assumed that the wastes could only convert into electricity. The efficiency of the practical energy potential was assumed to be 33%. The maximum potential was estimated by taking an efficiency of 50%. The conversion into commercial fuel was assumed to be 40%.

Cost estimates: Swisher and Wilson also projected the costs of renewable energy technologies and among them gasification and ethanol, methanol and biogas conversion. Table B3.1 presents the costs estimation of Swisher and Wilson.

Table B3.1: Costs of biomass conversion technologies from Swisher and Wilson (1993)

Energy technology	Present cost	Future cost	Unit
Biomass/STIG		0.05	$/kwh
Ethanol from sugar	8	6	$/GJ
Ethanol from wood	13	7	$/GJ
Methanol from wood	15	10	$/GJ
Biogas		1	$/GJ

Results:

Table B3.2 presents the estimation of the practical and maximum potential of Swisher and Wilson for 2030 for 20 regions.

Table B3.2a and B3.2b: Estimates of practical and maximum potential and practical potential of biomass energy from Swisher and Wilson (1993) in TWeh/yr (a) and EJ/yr (b) with efficiencies of 50% (maximum potential) and 33% (practical potential).

Table B3.2a.

Max eff 50%	Maximum potential		Practical potential	
Pract eff 33%	Residues	Energy Crops	Residues	Energy Crops
	2030	2030	2030	2030
World	12040	10348	7947	3657
Industrialized	4263	6204	2814	1830
Developing	7777	4144	5133	1827
Canada	319	800	211	233
USA	1347	2433	889	734
Nordic Countries	181	333	119	103
Western Europe	694	211	458	211
Eastern Europe	375	144	248	59
Former USSR	1111	1933	733	354
Japan	0	83	0	55
Australia/New Zealand	236	267	156	81
Mexico/Central America	458	167	303	84
Andean Countries	333	389	220	100
Brazil	1028	667	678	536
Southern Cone	250	211	165	105
China	1278	444	843	60
India	1403	211	926	62
Four tiger	28	0	18	0
ASEAN	569	189	376	103
Other Asia/Pacific	1014	489	669	17
Middle East	0	0	0	0
North Africa	83	44	55	40
Sub-Saharan Africa	1333	1333	880	720

Table B3.2b

	Maximum potential			Practical potential		
	Residues 2030	Energy Crops 2030	Total 2030	Residues 2030	Energy Crops 2030	Total 2030
World	86.69	74.51	161.19	86.69	39.89	126.59
Industrialized	30.69	44.67	75.36	30.70	19.96	50.66
Developing	55.99	29.84	85.83	56.00	19.93	75.93
		0.00		0.00	0.00	
Canada	2.30	5.76		2.30	2.54	
USA	9.70	17.52		9.70	8.01	
Nordic Countries	1.30	2.40		1.30	1.12	
Western Europe	5.00	1.52		5.00	2.30	
Eastern Europe	2.70	1.04		2.71	0.64	
Former USSR	8.00	13.92		8.00	3.86	
Japan	0.00	0.60		0.00	0.60	
Australia/New Zealand	1.70	1.92		1.70	0.88	
	0.00	0.00		0.00	0.00	
Mexico/Central America	3.30	1.20		3.31	0.92	
Andean Countries	2.40	2.80		2.40	1.09	
Brazil	7.40	4.80		7.40	5.85	
Southern Cone	1.80	1.52		1.80	1.15	
China	9.20	3.20		9.20	0.65	
India	10.10	1.52		10.10	0.68	
Four tiger	0.20	0.00		0.20	0.00	
ASEAN	4.10	1.36		4.10	1.12	
Other Asia/Pacific	7.30	3.52		7.30	0.19	
Middle East	0.00	0.00		0.00	0.00	
North Africa	0.60	0.32		0.60	0.44	
Sub-Saharan Africa	9.60	9.60		9.60	7.85	

B4. Name: Shell

(Shell 1995)

Timeframe: 1860-2060

Geographical aggregation: world

Background: In 1995 Shell International published two scenario of the future energy mixture. The scenarios were aimed to given an overview of the future global energy mixture.

Used Driving forces/scenario:

Shell used two contracting scenarios in their study on the evolution to the world's energy system 1860 – 2060. These scenarios were based on two energy visions for the future: In "Sustained Growth" abundant energy supply is provided at competitive prices as productivity in supply keeps improving in an open market context
In "Dematerialization", human needs are met through technologies and systems requiring much lower energy input. The sustained growth scenario assumes that the challenge of providing abundant energy at competitive prices would be met over the next decades. So new technologies would steadily progress along their learning curves, first capturing niche markets and, by 2020 become fully competitive with conventional energy sources.
The dematerialization scenario assumes that thanks to advances in materials and design capabilities, objects and equipment will fulfill their function using ever less or lighter material. In the dematerialization scenario, the rate of market penetration for identified renewable energy like biomass is lower than in "sustained growth scenario".

Energy demand: In the sustained growth scenario the amount of energy per capita reaches 0.33 TJ and in the dematerialization scenario an amount of 0.12 TJ is reached, giving a total demand of respectively1500 EJ and 900 EJ.

Population: Both scenarios assume the same population growth. It was assumed that world population reaches 8.5 billion in 2030 and 10 billion in 2060.

GDP: The GDP was assumed to reach $17000 by 2060.

Types of biomass sources included

The type of biomass included was not specified.

Conversion technologies included: Both conversion in electricity and liquid fuels was mentioned, although how it was included in the study was not described.

Cost estimates: Cost reductions reflect an 85% for biomass and it was assumed that these costs could be reduced by advances in clonal propagation and genetic enhancement of plants, notable woody crops.

Conversion, first into electricity, and later into liquid fuels, could become commercial through small-scale replicable facilities. It was assumed that the biomass power costs range from 4.5 – 6.0 ¢/kWh (based on NREL).

Results:

The estimated total amount of biomass within the two scenarios are presented 220 EJ for the Sustained growth scenario and 200 EJ for the Dematerialization scenario.

B5. Name: AGLU
(Edmonds, Wise et al. 1996)

Timeframe: 1990-2100

Geographical aggregation: World, 11 regions

1. United States
2. Canada
3. Western Europe
4. Japan
5. Australia & New Zealand
6. Eastern Europe and Former USSR
7. China and Centrally planned Asia
8. Middle East
9. Africa
10. Latin America
11. Other South and East Asia

Background: The study had been done by using two models of MiniCAM 2.0 which is a set of models within the Pacific Northwest National Laboratory Global Change Assessment Model (GCAM) system. In this study, the energy model ERB (Edmonds-Reilly-Barns) and the land use model AGLU (Agriculture-Land-Use) module were used. The AGLU is a dynamic market equilibrium model. The model employs information on supplies and demands of crops, livestock and forest products to develop estimates of market clearing prices.
The model includes an option for trade.

Used Driving forces/scenario:
Within the model some key assumptions had been made on energy and economy. It was chosen to have assumptions that are consistent with the IS92a developed by the IPCC. It was furthermore assumed that the biomass energy industry comes into existence after the year 2005 as in the IS92a.

Population: It was assumed that the global population in 2100 reaches 11 billion.

Economy: it was assumed that the global yearly GNP growth is 2.3%.

Types of biomass sources included

Within the study a difference is made between traditional biomass (fuelwood) and modern biomass (crop residues as well as energy crops). The modern biomass demand was simulated in the energy model. The fuelwood demand was simulated by the land use model. The land use model allocates land based on the rate of return. The rate of return is calculated based on the average potential productivity, the price to consumer of the product and the average cost of per unit land of production.

Energy Crops: The use of energy crops was included.

Yield: It was assumed that the potential productivity of a crop depends on a variety of regional defined factors, including technology, climate, the concentration of atmospheric CO2 and fertilization. Except for the technological change, which is entered as an exogenous assumption for each period, all factors were kept 1 in this version of MiniCAM 2.0. The rate of exogenous productivity improvement for managed forests and fuelwood was set at 0.5%/yr. The biomass productivity was assumed to increase from 6 Mg $ha^{-1}yr^{-1}$ unto 10 Mg $ha^{-1}yr^{-1}$.

Available area: Land is partitioned into two fundamental categories: managed and less managed lands. Less managed lands in turn are composed of those lands which could potentially become managed for production of goods and services, and those which are "parked", i.e. withheld from human development. The production of a product, and among them biomass energy crops is simulated by assuming that it can use part a fraction of the land not being less managed land or needed for habitat. This fraction depends on the rate of return.

Agricultural residues: The use of crop residues for modern biomass was included. It was mentioned that for the production, crop residues are assumed to be available up to a maximum of V per unit land, beginning at a cost V_{min} per region and time and rising linearly to V_{max} per region and time at full harvest of residues. However, the exact numbers were not included in the report, as well as the definition of full harvest.

Results:

The production of modern biomass in the global energy mixture was expressed in a graph. For this study the figures from the graph were converted into Table B5.1 which presents the commercial biomass Energy production by region. It was simulated by the energy model that modern commercial biomass would fulfill by the year 2095 more than 125 EJ/yr of the world's energy needs (70 EJ/yr by the year 2050).

Table B5.1: Commercial Biomass Energy Production by region EJ/yr.

Regions	Production (EJ/yr)	
	2050	2100
Other South & East Asia	9	18
Latin America	9	14
Africa	22	34
Middle East	1	2
China	1	4
E Europe and Former USSR	16	27
Australia & New Zealand	4	7
Japan	0	0
W Europe	4	7
Canada	4	5
United States	7	11
World	77	129

Furthermore it was concluded that international trade in crops continues to grow over time. Three regions are net importers of crops over the entire course of the next century: the Middle East, Latin America, and Other South and East Asia. The case of Latin America and other South and East Asia is different. Land is not constraint in these regions.

Commercial energy production is a relatively secondary consumer of land, though land used in commercial biomass grows to the point that in 2095 almost as much land is in biomass energy (740 Mha) as in crop productivity (960 Mha). But this is as much owing to the shift away from land in crops as it is to the increased shift toward land in commercial biomass.

B6. Name: GLUE

(Yamamoto, Yamaji et al. 1999) and (Fujino, Yamaji et al. 1999)

Timeframe: 1975 – 2100

Geographical aggregation: World, aggregated in two regions: developing and developed region

Background: The Global Land-use and energy model (GLUE) is a model described by the SD technique (system dynamic). It consists of a land-use sub-model and an energy sub-model. The land-use sub-model considers the wood and food sector and includes land competition among various uses of biomass applications such as paper, timber, food, feed and timber. The energy sub-models was developed following the structure of the Edmonds-Reilly model. The supply of modern bioenergy calculated in the land-use sub-model is substituted for demand of coal in the energy sub-model. The energy sub-model handles only commercial energy. The land-use sub-model handles not only commercial energy including modern bioenergy, but also non-commercial energy including traditional bioenergy.
The results of the simulation were given in Biomass balance Tables.

Used Driving forces/scenario:

To simulate the biomass energy potential by using GLUE, there have been made assumptions on main input data like population it was assumed that the population would be 10,0 in 2050 and reach 11,6 billion in 2100.

Types of biomass sources included

The potential study of GLUE consists of the energy crops and all forms of biomass residues except the material-recycled portion of the sawmill residues, timber scrap, board scrap and paper scrap.

Energy Crops: It was assumed that potential of energy plantation is sensitive to food supply and demand.

Yield: It was assumed that the crop productivity in general would increase with a factor of 1.74 (2050) and 1.77 (2100) in developed regions and 2.19 (2050) and 2.49 (2100) in developing regions**.**

Available area: Energy crops could grow on surplus arable land, that means land not needed for food production. It was assumed that both the developed as developing regions had an additional arable land. It was assumed that in the developing region the current fallow land (68 Mha) was converted to arable land. For the developing regions the arable area was assumed to double in 2100 by diverting 30% of deforestation area to arable land and to convert degraded area (756 Mha) to arable land. Both assumptions were taking from literature.

Residues: Both primary as secondary forest residues were included in the study. Table B6.1includes the assumed discharge rates of biomass residues in the reference case.

Table B6.1: Discharge rates of biomass residues in the reference case

	Unit	Discharge area	Energy use rates (before 2000)	Practical energy usable rates
Woody biomass				
Roundwood harvesting residues	t/t	0.51 of biomass stock	0	0.50
Fuelwood harvesting residues	t/t	0.36 of biomass stock	0	0.00
Black liquor	J/J	0.44 of pulpwood	1	1.00
Sawmill residues	J/J	0.49 of roundwood (dev. ed)	0	0.42 (dev. ed)
	J/J	0.34 of roundwood (dev. ing)	0	0.75 (dev. ing)
Paper scrap	t/t	0.26 of paper stock/yr	0	0.10
Scrap of timber and board	t/t	0.03 of timber stock/yr	0	0.75
Food biomass				
Cereal residues	t/t	1.3 of cereals	0	0.25
Sugarcane harvesting residues	t/t	0.150 of sugarcane	0	0.67
Bagasse	t/t	0.283 of sugarcane	1	1.00
Animal dung	J/J	0.3 of feed input	0	0.25
Kitchen refuse	J/J	0.2 of food supply	0	0.75
Human feaces	J/J	0.2 of food supply	0	0.25
Chemical products				
Chemical products scrap	t/t		0	0.75

Results:

Table B6.2 presents the results of the potential assessment of GLUE in 2100.

Table B6.2 : The results of the potential assessment of GLUE in 2100

	Unit	Energy crops	Biomass residues	Total
Developed regions	EJ/yr	100	49	149
Developing regions	EJ/yr	54	223	277
World	EJ/yr	154	272	426

B7. Name: USEPA

(Lashof and Tirpak 1990)

Timeframe: 1985 - 2100

Geographical aggregation: World

Background: In 1990 the US Environmental Protection Agency came out with a document on policy options for stabilizing global climate in which scenario simulations had been undertaken. To simulate four types of scenarios, an integrated analytical framework was developed. This framework consisted of four emission modules and two concentration modules. One emission module includes an energy module which consists of a Global Energy Supply Model (SUPPLY), based on Edmonds and Reilly. Furthermore a DEMAND model is included. Furthermore and land-use and natural source module is included. It was mentioned the modules of the framework are not fully integrated.

Used Driving forces/scenario:

Within the study four scenarios of future patterns of economic and technological development have been constructed. These four scenarios differ in the assumptions on the rate of economic growth and the adoption of policies that influence climate change. Two scenarios explore alternative pictures of how the world may evolve in the future assuming the policy choices allow unimpeded growth in emissions of greenhouse gases (No Response scenarios); The Rapid Changing World (RCW) scenario and the Slowly changing world (SCW) scenario. The RCW assumes rapid economic growth and technical change; the SCW assumes more gradual change. Furthermore two extra scenarios have been introduced based on RCW and SCW, however with the option of stabilizing policies. It was assumed that solar and biomass energy would penetrate the market and furthermore deforestation and increasing energy efficiency was assumed.

Population: It was assumed that within the RCW the population reaches 11.0 billion[4] people. For the SCW this was assumed to be 13.6 billion [5]

Economic: It was assumed that the economic grows in two time series, as can be seen in Table B7.1.

Table B7.1: the economic growth assumptions in the two scenarios

	SCW		RCW	
	1985-2025	2025-2100	1985-2025	2025-2100
US&OECD	1.7	1.0	2.7	1.5
USSR & E-Europe	2.2	1.6	4.3	2.6
Centrally planned Asia	3.2	2.5	5.1	4.0
Other dev. countries	2.7	2.1	4.5	3.3
World	2.0	1.5	3.4	2.6

[4] Own measurements from graph
[5] Own measurements from graph

Types of biomass sources included

In the report two types of biomass energy are mentioned; traditional biomass energy and modern biomass energy. Within the scenario only energy crops is included [6].

Energy Crops: Assumptions made on the potential of energy crops were based on assumptions made on land availability and productivity.

Yield: It was stated by (Kayes 1993) that various degrees of improvement in current productivity rates were postulated by (Lashof and Tirpak 1990).

Available area: It was assumed that 10% of the total (global) forest and woodland area plus 10% of total cropland area would be technically available for biomass energy development, a total of 556 Mha.

Conversion technologies included: It was assumed that conversion efficiencies improve to 75% after 2010.

Cost estimates: It was assumed that the prices for gaseous fuels from biomass fall to $ 4.35/GJ ($1988) after 2010, and liquid fuel from biomass to about $6.00/GJ.

Results:

(Kayes 1993) stated that the total production of biomass is then constrained to a level far below that deriving from the assumptions about area and protected productivity rates. The results of the biomass inputs in terms of primary energy supplied by biomass under the various scenarios are given by (Kayes 1993)and (Lashof and Tirpak 1990) and presented in Table B7.2. The data from (Lashof and Tirpak 1990) are taking from a graph which may cause the difference between both references.

Table B7.2: Primary biomass energy supply according the (Lashof and Tirpak 1990) (taken from graph) and in parenthesis from (Kayes 1993)

scenario	1985	2000	2025	2050	2075	2100
RCW	0	0		45 (13)	55 (62)	74 (68)
SCW	0	0		18 (7)	30 (37)	55 (48)
SCWP	0	0		100 (35)	140 (205)	194 (248)
RCWP	0	0		220 (136)	285 (237)	295 (273)

[6] Within the main report a description on types of biomass and how they are treaded was found. However (Kayes 1993) describes the U.S. EPA study based on U.S. EPA “Policy options for stabilizing global climate” Report to congress **main report** 21P.20003.1, US Environmental Protection Agency, Washington D.C., December 1990 and on U.S. EPA “Policy options for stabilizing global climate” Report to congress **technical appendices** 21P.20003.3, US Environmental Protection Agency, Washington D.C., December 1990. We failed in finding those report. We continue in describing the U.S. EPA work based on the descriptions by Kayes

B8. Name: Hall

(Hall, Rosillo-Calle et al. 1993)

Timeframe: 2025

Geographical aggregation: World, 10 regions

Background: David Hall has studied and discussed the potential of biomass resources in various studies, among them the study included in (Johansson, Kelly et al. 1993) which is included in this report.

Used Driving forces/scenario:

(Hall, Rosillo-Calle et al. 1993) did not use a scenario or further driving forces within the potential assessment.

Types of biomass sources included

Within his assessment of the potential world wide bioenergy sources, (Hall, Rosillo-Calle et al. 1993) divides the biomass resources in three main categories which can be further subdivided.

- Biomass residues:
  - Crop residues
  - Dung residues
  - Forest-product industry residues
- Biomass from existing forests
- Biomass plantations for energy

Energy Crops: It was stated that the potential of energy crops depends on the productivity and the available area.

Yield: It was stated that estimating the average yields that can be sustained over large areas and over long periods is difficult because experience is limited. Average yields will be less than in the tropics because the growing season is shorter and most plantations will be C3 plants. Offsetting these disadvantages is the prospect that most plantations will be established on relatively high quality cropland. In light of such considerations, average yields of 10-15 tonnes per hectare per year may be expected during the first quarter of the next century and 15 to 20 tonnes per hectare per year in the second quarter. For his potential assessment HALL assumes an average yield of 15 tonnes/ha/yr.

Available area : It was stated that by the middle of the 21ste century, some 890 Mha or 10% of the world's land area now in cropland, forests and woodland, and permanent pasture (or 7% of total world land area) might be put into biomass production for energy.

Residues: (Hall, Rosillo-Calle et al. 1993) included forest and agricultural residues as well as dung in his assessment. It was stated that while the generation rate for biomass residues is large, not all residues could be utilized for energy purposes. The assumptions made on recoverability are presented in Table B8.1.

Table B8.1: Assumptions on recoverability on crop residues

Agricultural residues except sugarcane	25% of generation rate
Sugarcane	All bagasse plus 25% of tops and leaves are recoverable
Dung	12.5%
Forest residue	25% of logging residues plus 33% of mill and manufacturing residues are recoverable

Results:

The results are presented in Table B8.2.

Table B8.2: Results of biomass resource potential in EJ/yr

	Energy crops	Crop residues	Forest residues	dung	total residues	Total
World	266.90	13.70	12.50	5.10	31.30	298.20
Industrialized	111.50	8.20	4.30	1.50	14.00	125.50
Developing	155.40	5.50	8.20	3.60	17.30	172.70
US/Canada	34.80	3.80	1.70	0.40	5.90	40.70
Europe	11.40	2.00	1.30	0.50	3.80	15.20
Japan	0.90	0.20	0.10		0.30	1.20
Australia+NZ	17.90	0.20	0.30	0.20	0.70	18.60
Former USSR	46.50	2.00	0.90	0.40	3.30	49.80
Latin America	51.40	1.20	2.40	0.90	4.50	55.90
Africa	52.90	1.20	0.70	0.70	2.60	55.50
China	16.30	0.90	1.90	0.60	3.40	19.70
Other Asia	33.40	2.20	3.20	1.40	6.80	40.20
Oceania	1.40					1.40

B9. Name: SEI/Greenpeace
(Lazarus, Greber et al. 1993)

Timeframe: 1988-2100

Geographical aggregation: Based on the Edmonds-Reilly energy-CO_2 model of regional breakdown (Edmonds & Reilly 1986), with some modifications.

AFR	Africa
CPA	Centrally Planned Asia (China, Laos, Cambodia, Vietnam, N. Korea)
EE	Central and Eastern Europe
JANZ	JANZ/OECD Pacific (Japan, Australia, New Zealand, Fiji
LA	Latin America
ME	Middle East
SEA	South and East Asia (all other Asian countries)
US	United States
USSR	Former USSR, now CIS and adjoining states
WE	Western Europe and Canada

Background: The SEI/Greenpeace study is produced by the Stockholm Environmental Institute –Boston Center, for Greenpeace International. The energy scenario is constructed given certain guidelines: (i) fossil fuels are phased out by 2100; (ii) nuclear energy is phased out by year 2010; (iii) no carbon removal technologies; (iv) narrowed GDP gap between North and South from 14:1 to 2:1 over the scenario period.

To facilitate comparison with other energy scenarios, assumptions about key driving forces – population growth and and global GDP– are the same as the then recent IPCC projections.

New renewable technologies are subject to environmental restrictions. With regard to biomass energy this implies that: "... biomass for energy would only be produced in a sustainable manner, with no net carbon emissions to the atmosphere. Biomass productivities were thus assumed to be considerably lower than in other studies". In addition, no municipal waste incineration was considered.

Biomass production is assumed to occur in the region of biomass demand. Hence, no trade in biomass for energy is assumed.

Used Driving forces/scenario:
Population growth, taken from the World Bank (Bulatao, *et al.* 1989).
Global GDP growth, taken from the IPCC 1990 (Swart, *et al.*1991) . IPCC 1990 assumptions about regional growth rates up to 2010. After 2010 the global GDP is redistributed among regions to reach the goal of a GDP gap between highest and lowest at 2:1 in 2100.

Types of biomass sources included

Energy Crops: Energy crops are specified to be mainly herbaceous and short rotation woody crops. No indication of species selection.

Yield levels[7]**:** Yields vary between regions, and are calculated based on assumed relative contribution from three specified biomass production systems. The regional yield levels are fixed over the whole scenario period in the base case. In an alternative scenario variant, a doubling of biomass yields is phased in over a 40 year period. Biomass yield are taken to be in the mid-range of values found in a literature survey (table G-3, page 227). The yield levels used is stated to be consistent with sustained wide scale applications worldwide (reference to (Hall 1991, Johansson, *et al.*1993)). Given relative contribution of bioenergy plantations from different regions, global average yield levels can be calculated (Table B9.2, B9.3 and B9.4).

Table B9.2: Global average yield levels. Base case productivity

	2000	2010	2030	2100
Global average yield (dry Mg ha^{-1})	11.8	12.0	11.7	12.2

Table B9.3: Three specified biomass production systems

	Wood yield (dry Mg ha^{-1})
Temperate wood	10
Moist tropical wood	20
Dry tropical wood	4

Table B 9.4: Regional yield levels and relative contribution of the three specified biomass production systems. Base case.

	AFR	LA	ME	SEA	CPA	US	JANZ	WE	USSR	EE
Biomass yield (dry Mg ha-1)	12	15.2	5.6	17.5	14.9	11	11	10	10	10
Temperate wood	0	0	0	0	50	90	90	100	100	100
Moist tropical wood	50	70	10	85	50	10	10	0	0	0
Dry tropical wood	50	30	90	15	0	0	0	0	0	0

a Land type basis: For tropical countries; comparison of freshwater available per unit available land, combined with judgement. US/JNAZ reflects warmer climate.

[7] It should be noted that the assumptions on yield have been made at the end, aiming to discuss the feasibility of the projected potentials.

Area dedicated to energy crops: The land requirements for energy crops production is a function of region-specific bioenergy demand, possible contribution from organic residues, and the assumed yield levels. Wind and solar technologies supply much of the increase in energy demand from 2030 to 2100. It is not clear whether growth in bioenergy demand is limited due to the rapid expansion of wind/solar technologies, or due to an exogenously defined upper limit on bioenergy supply. Table B9.5 shows the plantation area requirement in different regions.

TableB9.5: Plantation area required in different regions in order to supply the demanded biomass at given yield levels (million hectares). Global totals and regional breakdown for the base case, and global totals for two alternative scenario variants[8]

	2000	2010	2030	2100
AFR	17	20	31	151
CPA	12	22	34	93
EE	6	9	23	22
JANZ	5	9	12	8
LA	13	18	28	58
ME	4	8	16	49
SEA	24	34	63	201
US	40	39	66	47
USSR	15	24	51	47
WE	21	34	59	45
Total	156	215	384	721
Total, with 16 EJ residues	136	179	316	652
Total, doubled productivity and 16 EJ residues	106	118	158	326

Residues

Forest residues: No residues (except sugarcane residues for cogeneration) are used in the base case. In two alternative scenario variants residue utilization is increased from 0 to 16 EJ over a 40 year period. Reference is given to (Hall, *et al.*1992) , who estimate current recoverable residues to amount to 65 EJ. The share of residues used that comes from forest or agriculture is not specified. The regional distribution of residues utilization is not specified.

Agricultural residues: For some regions utilization of sugarcane residues for cogeneration of heat and electricity contribute to the bioenergy supply. The authors refer to a projection of the electricity generation potential in the sugarcane industry in developing countries year 2027 (Ogden, *et al.*1990) . 25 percent of the projected potential for year 2027 was assumed to be realized in 2030. The amount of electricity generated in the sugarcane industry in 2100 is not given. Also, se comments under section treating forest residues.

[8] In the alternative scenario variants, doubled productivity and use of 16 EJ residues is phased in over a 40 year period.

Municipal waste: No municipal waste incineration was considered[9].

Traditional bioenergy: A full transition from traditional biomass fuels in developing countries to more convenient fossil and renewable fuels is postulated. In urban areas, complete fuel switching to modern fuels (including biofuels) occurs by 2030. In rural areas the transition is complete after 60-70 years, except in Middle East and Latin America, where it is complete around 2030.

Conversion technologies included: It was stated that biomass can be used for electricity generation and liquid fuels production, or used directly as a solid fuel. Biomass Integrated Gasifier Steam-Injected Gas (BIG-STIG) turbine cogeneration systems run at 62.1 percent efficiency –with 48.4 percent going to electricity and 51.6 percent to steam– (reference to (Ogden, *et al.*1990)). Conversion of biomass into biogas (for electricity generation and other uses) is assumed to be 85 percent efficient.

Biomass is converted into alcohol and other biomass-derived fuels with an efficiency of 50 percent. Conversion efficiency is assumed to rise to 60 percent by 2010.

Cost estimates: No direct account of pricing mechanisms upon energy consumption patterns in the modelling. A wide range of studies assessing the cost of energy efficiency technologies and renewable energy sources, provided the basis for assumptions about cost-efficiency of such options. It is stated that: "...projections of renewable energy supply costs indicate that solar, wind, and biomass technologies could be close enough to those of fossil fuels to enable a transition to occur without major economic penalties". In an alternative modelling approach (Waide 1992), using a model[10] which has been extensively used for long-range energy assessments by the IPCC and USEPA, it was found that the FFES could be achieved at a cost equal to or less than 'business-as-usual'. For biomass energy costs, the authors refer to (EPRI 1989, SERI 1990, DeLuchi, *et al.*1991, UCS 1991) .

Results:

Total biomass supplies for energy for the FFES is given in table B9.6 below. No biomass residues other than sugar cane residues for cogeneration is assumed to be used in the base case. Thus, the major part is provided by dedicated energy crops production. In alternative scenarios, utilization of 16 EJ of biomass residues is phased in over a 40 year period. Biomass production is assumed to occur in the region of biomass demand.

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[9] Landfill methane is mentioned as a biomass energy source (page 141). Use of landfill methane is not explicitly reported, but it could in principle be included in the 16 EJ of residues used for energy in the alternative scenarios.

[10] The model, an adapted macro-economic global energy model, is refered to as: the Atmospheric Stabilization Framework –ASF (ICF 1990).

Table B9.6: Total primary biomass energy supplies for the FFES (EJ)

	2000	2010	2030	2100
AFR	4.3	5.1	8	37.3
CPA	3.9	6.8	10.6	29
EE	0.7	1	2.6	2.5
JANZ	1.7	3	4.3	3
LA	5.3	6.8	11.4	23.5
ME	0.8	1.7	3.6	10.7
SEA	6.3	8.3	15.6	47.8
US	8	7.7	13.1	9.3
USSR	2.9	4.7	10.2	9.3
WE	4.2	6.7	11.8	9
Total	38.1	51.8	91.2	181.4

B10. Name: RIGES

(Johansson, Kelly et al. 1993)

Timeframe: 1985-2050

Geographical aggregation: The geographic aggregation is based on (IPCC 1991),with two modifications: OECD Europe/Canada is separated into OECD Europe and Canada, and OECD Pacific is separated into Japan and Australia/New Zealand.

Africa
Latin America
South and East Asia
Centrally Planned Asia
Japan
Australia/New Zealand
United States
Canada
OECD Europe
Former Centrally Planned Europe
Middle East

Background: The Renewables-Intensive Global Energy Scenario (RIGES) is included as an appendix to chapter 1 in the often cited "Blue book" on renewable energy (Johansson, *et al.* 1993), which was prepared as an input to the 1992 United Nations Conference on Environment and Development. The approach in the biomass part of RIGES is similar to the approach of the HALL assessment, which is included as chapter 14 in (Johansson, *et al.* 1993). The major difference is that while HALL refer to present data in estimating the residue potential, the RIGES estimate is based on assumptions about changes in agriculture and forestry up to 2050. Both HALL and RIGES refer to estimates of areas of tropical lands requiring replenishment of forest cover (Grainger 1988), and surplus cropland in industrialized countries in their estimate of land availability for energy crops productions.

Used Driving forces/scenario:

The aim of the RIGES is to explore: " ...the prospects for renewables in a world where future living standards are much higher than at present". Therefore, the high economic growth variant in (IPCC 1991) is used. Since energy efficiency is emphasized in RIGES, electricity consumption and direct fuel use projections of one of the high efficiency variants in (IPCC 1991) (the accelerated policies scenario) is adopted as demand projection for the RIGES.

The population projection used by (IPCC 1991), and adopted for the RIGES, is taken from (Zacharia & Vu 1988).

On the biomass supply side, sugarcane and industrial round wood production (and consequently related residues flows) increases with population, and thus more slowly than the economy. Urban refuse also increase with population, and is only considered for industrialized countries. Roundwood production for fuelwood and charcoal is assumed to be constant at 75 percent of the 1985 level over the whole scenario period

Future production of cereal residues and dung is based on the IPCC (1991) projections for cereals and animal products.

Types of biomass sources included

Energy Crops: The areas used for plantations, and the corresponding yield levels, in RIGES year 2025 and 2050 are given in table B10.4 below. Africa and Latin America have 69 and 63 percent of global plantation areas in 2025 and 2050 respectively. On a per capita basis, Latin America and Canada have significantly larger plantation areas than the other regions.

Table B10.2 Areas used for plantations, and corresponding yield levels in RIGES

	Area (Mha)		Area (ha/cap.)		Yield (Dry Mg ha^{-1} yr^{-1})	
	2025	2050	2025	2050	2025	2050
Africa	95	106	0.06	0.05	10	15
Latin America	161	165	0.23	0.20	10	15
South and East Asia	-	-	-	-	-	-
Centrally Planned Asia	25	50	0.01	0.03	10	15
Japan	-	-	-	-	-	-
Australia/New Zealand	-	-	-	-	-	-
United States	32	32	0.11	0.11	15	15
Canada	6	6	0.21	0.21	10	10
OECD Europe	30	30	0.07	0.07	15	15
Former CP Europe	20	40	0.04	0.08	10	15
Middle East	-	-	-	-	-	-
Total	369	429	0.05	0.05	10.8[iii]	14.9[a]

Yield levels: In 2025 all regions with bioenergy plantations, except United States and OECD Europe, are assumed to have a yield level at 10 dry Mg per hectare and year. For United States and OECD Europe the yield level is assumed to be 15 dry Mg per hectare and year. In 2050, all regions with bioenergy plantations, except Canada, have reached the yield level 15 dry Mg per hectare and year. Yield levels in Canada is 10 dry Mg per hectare and year over the whole scenario period.

No reference is given in order to justify the assumptions about yield levels. However, the HALL assessment (Hall, *et al.*1993) , which is included in the same book as the RIGES, serves as an implicit basis for the assumption in RIGES (see the overview of the HALL assessment included in this appendix).

Area dedicated to energy crops: It is assumed that in industrialized countries, bioenergy plantations are located primarily on excess agricultural lands. For United States, the area assumed to be used for bioenergy production (32 Mha) is equal to the amounts of land held out of agricultural production for the Acreage Reduction Program (18 Mha) , and the Conservation Reserve Program (14 Mha). For the European Community it is stated that more than 15 Mha of land will have to be taken out of farming by 2000 if the surpluses and subsidies associated with the Common Agricultural Policy are to be brought under control, and in the future excess cropland in the EU could increase to as much as 50 Mha (Johansson, *et al.*1993, page 56-57) . No basis is given for assumptions about land availability in other industrialized regions.

For developing countries, it is assumed that bioenergy plantations are located primarily on deforested or otherwise degraded lands that are not needed for food production. For Africa and Latin America, the authors refer to (Grainger 1988).

Africa: 842 Mha of degraded lands, with all of the degraded lands involving logged forests (39 Mha), humid tropics forest fallows (59 Mha), and deforested watersheds (3 Mha) are suitable for reforestation. It is also noted that Grainger (1988) estimates that one fifth of desertified dry lands globally are potentially available for reforestation. If applicable to Africa, this corresponds to an additional 148 Mha that could be deforested.

Latin America: 318 Mha degraded lands, with all of the degraded lands involving logged forests (44 Mha), humid tropics forest fallows (85 Mha), and deforested watersheds (27 Mha) are suitable for reforestation. It is also noted that Grainger (1988) estimates that one fifth of desertified dry lands globally are potentially available for reforestation. If applicable to Latin America, this corresponds to an additional 32 Mha that could be deforested.

For China, the authors refer to deforested lands on low-lying mountains that are already targeted for reforestation. It is noted that China has announced reforestation goals implying an increase from the 1983-85 level of forest cover of 52-145 Mha.

As with other assumptions related to bioenergy, the HALL assessment can be regarded an implicit basis.

Residues: Biomass energy supplies from residues and urban refuse is given in Table B10.3 and B10.4 below.

As noted above, South and East Asia supply significant amounts of biomass energy in the form of residues, mainly due to the large population. Latin America also supply large amounts of residue biomass, thanks to high per capita dung and sugarcane residue generation rates and a fairly large population..

Australia/New Zealand have very high per capita agricultural residue generation rates, and Canada have very high per capita residue generation rates related to cereals and industrial round wood production. However, since the populations in Australia/New Zealand and Canada are relatively small, this has no large impact on the global totals.

Table B10.3: Biomass supplies from residues and urban refuse for the RIGES (EJ)

	Forestry residues			Agricultural residues							
	Industrial		Fuel-Wood	Sugarcane		Dung		Cereals		Urban refuse	
	2025	2050	2025/ 2050	2025	2050	2025	2050	2025	2050	2025	2050
Africa	0.72	0.98	0.78	1.17	1.58	3.46	5.19	0.68	0.85	-	-
Latin America	0.87	1.01	0.51	5.33	6.19	3.23	4.18	0.98	1.70	-	-
South and East Asia	0.95	1.12	1.00	3.20	3.79	6.12	11.53	2.34	2.98	-	-
Centrally Planned Asia	0.78	0.84	0.39	0.32	0.35	1.23	1.39	1.13	1.19	-	-
Japan	0.20	0.19	-	-	-	-	-	0.16	0.23	0.53	0.53
Australia/New Zealand	0.15	0.15	0.00	0.18	0.18	0.48	0.62	0.27	0.38	0.063	0.062
United States	2.18	2.14	0.20	-	-	0.62	0.41	1.72	1.81	1.14	1.12
Canada	0.96	0.95	0.01	-	-	-	-	0.35	0.35	0.11	0.11
OECD Europe	1.28	1.27	0.10	-	-	0.76	0.8	1.41	1.41	1.30	1.28
Former CP Europe	2.18	2.28	0.19	-	-	1.10	1.14	1.81	2.07	-	-
Middle East	0.18	0.23	0.00	-	-	-	-	-	-	-	-
Total	10.4	11.2	3.2	10.2	12.1	17.0	25.3	10.8	13.0	3.1	3.1

Table B10.4: Biomass supplies from residues and urban refuse for the RIGES (GJ/cap)

	Forestry residues				Agricultural residues							
	Industrial		Fuel wood		Sugarcane		Dung		Cereals		Urban refuse	
	2025	2050	2025	2050	2025	2050	2025	2050	2025	2050	2025	2050
Africa	0.5	0.5	0.5	0.4	0.8	0.8	2.3	2.6	0.5	0.4	-	-
Latin America	1.2	1.2	0.7	0.6	7.5	7.5	4.5	5.0	1.4	2.1	-	-
South and East Asia	0.4	0.4	0.4	0.3	1.3	1.3	2.4	3.8	0.9	1.0	-	-
Centrally Planned Asia	0.5	0.5	0.2	0.2	0.2	0.2	0.7	0.7	0.7	0.6	-	-
Japan	1.4	1.4	-	-	-	-	-	-	1.2	1.7	3.8	3.8
Australia/New Zealand	6.8	6.9	0.0	0.0	8.2	8.3	21.8	28.4	12.3	17.4	2.9	2.8
United States	7.5	7.5	0.7	0.7	-	-	2.1	1.4	6.0	6.4	3.9	3.9
Canada	33.7	33.7	0.4	0.4	-	-	-	-	12.3	12.4	3.9	3.9
OECD Europe	2.8	2.8	0.2	0.2	-	-	1.7	1.8	3.1	3.1	2.9	2.8
Former CP Europe	4.4	4.4	0.4	0.4	-	-	2.2	2.2	3.6	4.0	-	-
Middle East	0.6	0.6	0.0	0.0	-	-	-	-	-	-	-	-
Total	1.2	1.2	0.4	0.3	1.2	1.3	2.1	2.7	1.3	1.4	0.4	0.3

Forest residues: Residues associated with both industrial round wood production and round wood production for fuel wood and charcoal is assumed to be available for modern biofuel production. Industrial round wood production increases with population. Future round wood production for fuel wood and charcoal is assumed to be 75 percent of the 1985 level, as reported by (FAO 1986).

For all regions, residues generation is related to both industrial round wood production and round wood production for fuelwood and charcoal, using coefficients derived for the U.S. forest sector in the late 1970s:

- felling residues amounts to 39 percentage of felled timber
- wood processing residues amounts to 45 percent of industrial round wood.

50 percent of the forest residues and 75 percent of wood processing residues are assumed to be available for energy purposes. This results in forest residues generation rates of:
0.65 times industrial round wood production
0.32 times round wood produced for fuelwood and charcoal

Agricultural residues: Agricultural residues accounted for in RIGES are sugarcane residues, cereal residues, and animal dung. Sugarcane production is assumed to increase in proportion to the population. Cereal production levels are assumed to be those projected by the IPCC Response Strategies Working Group (IPCC 1990). Dung production is assumed to increase in proportion to meat production in all regions except South and East Asia and OECD Europe, where dung production increase in proportion to production of dairy products, as projected by (IPCC 1990).

Sugarcane residue generation is assumed to be 150 dry kg of bagasse (2.85 GJ) plus 279 dry kg of tops and leaves (5.30 GJ) per Mg cane. All the bagasse and two thirds of tops and leaves are available for energy purposes. In China residues from only half of sugarcane production are available for energy, due to the fact that cane residues are often used for papermaking in China.

Cereal residues generation is assumed to be 1.3 times cereal production (weight basis). 25 percent of the residues are assumed to be available for energy purposes (heating value=12 GJ/Mg).

Dung production is estimated based livestock inventories (FAO 1986), together with dung production coefficients and dung heating values reported for different animals by (Taylor, *et al.* 1982). It is assumed that 25 percent of the produced dung is recoverable.

Municipal waste: The use of urban refuse for energy is considered only for industrialized countries. It is assumed that the production rate per capita is constant, and that 75 percent of the produced urban refuse is available for energy purposes.

United States and Canada have an annual generation rate of 330 kg per capita (15.9 MJ/kg). Japan, Australia/New Zealand and OECD Europe have an annual generation rate of 300 kg per capita (12.7 MJ/kg).

Traditional bioenergy: It is assumed that in the period 2025 to 2050 wood from the natural forest is no longer used for traditional fuel wood and charcoal applications (e.g., cooking), but is instead used to produce electricity or modern fuels. Round wood production for such modern energy uses is set to 75 percentage of the 1985 level of round wood production for traditional fuel wood and charcoal applications –as reported by FAO (1986)– in order to: "...ensure that yields are sustainable".

Round wood production for traditional fuel wood and charcoal applications is assumed to generate forest residues to the same extent as industrial round wood production, and half of this is accounted for as forest residues. Therefore, the *total* amount of wood made available for modern energy uses via transformation of traditional round wood production is 99 percentage of the 1985 level of such activities.

Additional

As noted in the section about traditional bioenergy above, round wood production for traditional fuel wood and charcoal uses is assumed to be available for modern energy uses. Table B10.5 gives the round wood production for modern energy uses in the RIGES. Industrial round wood production, which is constant over the scenario period when expressed on a per capita basis, is included as a comparison. As can be seen, developing regions are expected to use more, or similar amounts of round wood for modern bioenergy as for regular forest products such as sawn wood, panels and paper. In industrialized countries on the other hand, industrial round wood production is much larger than round wood production for modern bioenergy. This is a direct consequence of the assumption that traditional bioenergy (which is the dominating use of wood in developing countries today) will be phased out, and the resource base will instead be available for modern energy uses.

Table B10.5 Primary biomass energy supplies from round wood for the RIGES

	Forest round wood (EJ)	Forest round wood (GJ/cap)		Industrial round wood production[iv] (GJ/cap)
	2025/ 2050	2025	2050	2025/2050
Africa	2.43	1.6	1.2	0.7
Latin America	1.59	2.2	1.9	1.9
South and East Asia	3.13	1.2	1.0	0.6
Centrally Planned Asia	1.21	0.7	0.6	0.7
Japan				2.2
Australia/New Zealand	0.02	0.9	0.9	10.5
United States	0.61	2.1	2.1	11.6
Canada	0.04	1.4	1.4	51.8
OECD Europe	0.31	0.7	0.7	4.3
Former CP Europe	0.58	1.2	1.1	6.7
Middle East	0.02	0.1	0.1	1.0
Total	9.94	1.2	1.0	2.0

Conversion technologies included: Regional production of biomass-derived fuels and electricity in the RIGES year 2050 is given in table B10.8 below. Most biomass is used for electricity generation and for fluid fuels production (especially methanol[11] and hydrogen, produced thermochemically).

It is assumed that advanced biomass-integrated gasifier/gas turbine (BIG/GT) power cycles with efficiencies of 43 percent become the norm by 2025, and biomass-integrated gasifier/fuel cell (BIG/FC) technologies with efficiencies of 57 percent become the norm by 2050. Methanol and hydrogen are produced at efficiencies of 62 and 70 percent in 2025, and 63 and 72 percent in 2050 respectively.

[11] Methanol is emphasized in the scenario because it is especially well suited for use with fuel-cell vehicles, which is assumed to become the technology of choice for road transportation in the period 2025 to 2050. However, it is acknowledged that also ethanol derived from cellulosic biomass feedstocks via enzymatic hydrolysis is a promising liquid biofuel.

Ethanol is produced from sugarcane at a rate of 70 liters (1.6 GJ) per Mg cane. Biogas is recovered from stillage at cane ethanol distilleries at a rate of 0.33 GJ per Mg cane. Biogas is produced from recoverable dung residues at a rate corresponding to 57 percent energy conversion efficiency.

Cost estimates: The energy demand and mix of primary energy supply is not generated via energy-economy modelling. Instead, the energy demand is taken from (IPCC 1991), and the scenario is then constructed based on the assumption that renewable energy technologies will capture markets whenever: "... 1) a plausible case can be made that renewable energy is no more expensive on a life cycle cost basis than conventional alternatives, and 2) the use of renewable technologies at the levels indicated will not create any significant environmental, land use, or other problems". Assumptions about the cost and performance of future renewable energy equipment are based on the analyses presented in chapters of the book.
It is stated that adoption of the set of technologies chosen for the RIGES would give rise to future energy prices that are much lower than those of most other long-term energy forecasts: the world oil price in 2030 would be similar to the then present level, the price of gas paid by utilities would double, and electricity price would decline somewhat. This is a consequence of renewables competing with conventional energy, bringing a downward pressure on energy prices.

Several of the chapters included in the book, presents data on costs for the production of biomass-derived fuels and electricity, and thus provide arguments for the statement about economic attractiveness of the RIGES. For example, the authors demonstrate two technological paths to the introduction of economically competitive biofuels in the transportation sector[12]:

-Ethanol from biomass via improved enzymatic hydrolysis technology for use in internal combustion engine vehicle applications (40 percent cost reduction relative to what could be achieved with present technology), and
-methanol and hydrogen production, via indirectly heated biomass gasifiers, for use in fuel cell cars.

Results:

Total biomass supplies for energy for the RIGES in years 2025 and 2050 is given in tables B10.6 and B10.7 below. Both liquid and gaseous fuels are traded. Africa, Latin America and Canada export biomass-derived methanol. Hydrogen produced from biomass is consumed within the region. Hydrogen produced from intermittent technologies are sometimes traded between regions.

Biomass plantations supply around 55 and 62 percent of global biomass supplies in years 2025 and 2050 respectively, with large regional variations. Africa and Latin America taken together produce around 64 percent of the total plantation biomass in both 2025 and 2050.

[12] The biomass feedstock price is assumed to be $3 per GJ (HHV basis)

South and East Asia have no plantations, but since this region is very populous the region supplies significant amounts of biomass energy in the form of residues. Latin America also supply large amounts of residue biomass, but here the reason is high per capita dung and sugarcane residue generation rates rather than a large population. Australia/New Zealand have very high per capita agricultural residue generation rates. But this has no large impact on the global totals, since the region has relatively low population. This notion also applies to Canada, which have very high per capita residue generation rates related to cereal and industrial round wood production, but relatively low population.

Table B10.6: Total primary biomass energy supply for the RIGES (EJ)

	Forests[v]	Residues[vi]		Plantations		Total	
	2025/ 2050	2025	2050	2025	2050	2025	2050
Africa	2.43	6.81	9.38	18.94	31.81	28.18	43.62
Latin America	1.59	10.92	13.59	32.30	49.60	44.81	64.78
South and East Asia	3.13	13.61	20.42	-	-	16.74	23.55
Centrally Planned Asia	1.21	3.85	4.16	5.00	15.00	10.06	20.37
Japan		0.89	0.95	-	-	0.89	0.95
Australia/New Zealand	0.02	1.14	1.39	-	-	1.16	1.41
United States	0.61	5.86	5.68	9.60	9.60	16.07	15.89
Canada	0.04	1.43	1.42	1.20	1.20	2.67	2.66
OECD Europe	0.31	4.85	4.86	9.00	9.00	14.16	14.17
Former CP Europe	0.58	5.28	5.68	4.00	12.00	9.86	18.26
Middle East	0.02	0.18	0.23	-	-	0.20	0.25
Total	9.94	54.82	67.76	80.04	128.21	144.80	205.91

Table B10.7: Total primary biomass energy supply for the RIGES (GJ/cap)

	Forests[vii]		Residues		Plantations		Total	
	2025	2050	2025	2050	2025	2050	2025	2050
Africa	1.6	1.2	4.5	4.6	12.6	15.7	18.8	21.5
Latin America	2.2	1.9	15.3	16.4	45.2	59.8	62.7	78.1
South and East Asia	1.2	1.0	5.4	6.8	-	-	6.6	7.9
Centrally Planned Asia	0.7	0.6	2.2	2.2	2.9	8.0	5.8	10.9
Japan			6.4	6.9	-	-	6.4	6.9
Australia/New Zealand	0.9	0.9	51.8	63.8	-	-	52.7	64.7
United States	2.1	2.1	20.3	19.9	33.2	33.7	55.6	55.8
Canada	1.4	1.4	50.2	50.3	42.1	42.5	93.7	94.3
OECD Europe	0.7	0.7	10.7	10.8	19.8	20.0	31.2	31.5
Former CP Europe	1.2	1.1	10.6	10.9	8.0	23.0	19.7	35.0
Middle East	0.1	0.1	0.6	0.6	-	-	0.7	0.7
Total	1.2	1.0	6.7	7.1	9.8	13.5	17.7	21.6

Table B10.8: Regional production of biomass-derived fuels and electricity in the RIGES year 2050

	Electricity (TWh/yr)		Solid fuels (EJ/yr)		Liquid fuels (EJ/yr)		Gaseous fuels (EJ/yr)	
	solid	MeOH	power	direct	MeOH	EtOH	H_2	biogas
Africa	589	104	4.2	-	21.53	0.13	-	2.99
Latin America	1332	162	10.29	-	22.3	0.5	10.61	2.48
South and East Asia	419	-	3.79	-	-	0.31	5.88	6.63
Centrally Planned Asia	671	-	4.35	9.91	2.97	0.06	-	0.79
Japan	-	82	-	-	0.6	-	-	-
Australia/New Zealand	20	-	0.18	-	0.383	0.015	-	0.353
United States	504	-	3.18	-	5.16	-	2.93	0.23
Canada	-	-	-	-	1.67	-	-	-
OECD Europe	529	-	3.34	-	3.15	-	3.59	0.46
Former CP Europe	1355	-	8.56	-	3.59	-	2.04	0.65
Middle East	-	-	-	-	-	-	-	-
Total	5419	348	37.89	9.91	61.35	1.02	25.05	14.58

B11. Name: LESS-BI

(Williams 1995)

Timeframe: 1990-2100

Geographical aggregation: The geographic aggregation is based on (IPCC 1991),with two modifications: OECD Europe/Canada is separated into OECD Europe and Canada, and OECD Pacific is separated into Japan and Australia/New Zealand.

Table B1.1: Regional breakdown

1. Africa	7. United States
2. Latin America	8. Canada
3. South and East Asia	9. OECD Europe
4. Centrally Planned Asia	10. Former Centrally Planned Europe
5. Japan	11. Middle East
6. Australia/New Zealand	

Background: The so called Low CO_2-emitting Energy Supply Systems (LESS), developed for the working group II of IPCC (Ishitani & Johansson 1996), include one biomass-intensive variant (LESS-BI). LESS-BI represents an extension of the Renewables-Intensive Global Energy Scenario (RIGES, which is also treated in this appendix), to the year 2100. There are some differences between LESS-BI and the RIGES. The LESS-BI scenario variant is based on 1994 estimates of remaining oil and gas resources of the US Geological Survey (Masters, *et al.*1994) , which are much higher than the 1990 estimates on which the RIGES projections were based. This results in much slower development of biomass synthetic fuels and consequently biomass energy in the near term (2025) than in the RIGES. The LESS-BI also includes CO2 sequestration in natural gas wells, which is not included in the RIGES.

Since LESS-BI is a modified and extended version of the RIGES, the approach is also in LESS-BI similar to the one used in the HALL assessment (Hall, *et al.*1993) , which is treated elsewhere in this appendix. The major difference is that while HALL refer to present data in estimating the residue potential, the LESS-BI estimate is based on assumptions about changes in agriculture and forestry up to 2100.

Used Driving forces/scenario:

The LESS-BI adopts the same energy demand projection as the RIGES –the high economic growth variant of the accelerated policies (AP) scenarios developed by the Response Strategies Working Group of the IPCC[13] (RSWG 1990). This means that also the population projections are from the same source: (Zacharia & Vu 1988).

As was noted in the introduction above, LESS-BI differs somewhat from RIGES regarding estimates of remaining oil and gas resources (much lower in the RIGES), and consideration of carbon sequestration in natural gas wells (not included in the RIGES). This leads to slower development of biomass synthetic fuels and consequently of biomass plantations in the near term (2025) than in the RIGES.

[13] Although, a different reference is given

The assumptions on the biomass supply side is almost identical to assumptions made in the RIGES:

Sugarcane and industrial round wood production (and consequently related residues flows) increases with population, and thus more slowly than the economy. Roundwood production for fuelwood and charcoal is assumed to be constant at 75 percent of the 1985 level over the whole scenario period.

Future production of cereal residues and dung is based on the IPCC (1991) projections for cereals and animal products.

Urban refuse also increase with population, Up to 2050, only urban refuse in industrialized countries is considered a source for energy. After 2050, also urban refuse in developing countries is included.

Types of biomass sources included

Energy Crops: The area used for plantations in LESS-BI are given in tables B11.2. Africa and Latin America dominate, but to a decreasing extent: 69 and 48 percent of global plantation area in 2025 and 2100 respectively. On a per capita basis, Latin America and Canada have significantly larger plantation areas than the other regions. The yield levels are given in table B11.3.

Table B11.2 Area used for plantations in the different regions

	Plantations (Mha)				Plantations (ha/cap)			
	2025	2050	2075	2100	2025	2050	2075	2100
Africa	25	47	94	114	0.02	0.02	0.04	0.05
Latin America	32	167	137	160	0.04	0.20	0.16	0.18
South and East Asia	5	17	23	53	0.00	0.01	0.01	0.02
Centrally Planned Asia	6	28	50	52	0.00	0.02	0.03	0.03
Japan	0	0	0	0	0.00	0.00	0.00	0.00
Australia/New Zealand	0	0	6	20	0.00	0.00	0.27	0.92
United States	0	42	46	55	0.00	0.15	0.16	0.19
Canada	1	11	11	13	0.03	0.39	0.39	0.46
OECD Europe	7	32	32	33	0.02	0.07	0.07	0.07
Former CP Europe	6	40	64	73	0.01	0.08	0.12	0.13
Middle East	0	0	0	0	0.00	0.00	0.00	0.00
Total	83	385	461	572	0.01	0.04	0.05	0.05

Table B11.3: Yield levels in the different regions

	Yield (Dry Mg ha^{-1} yr^{-1})			
	2025	2050	2075	2100
Africa	10	15	20	20
Latin America	10	15	20	20
South and East Asia	10	15	20	20
Centrally Planned Asia	10	15	20	20
Japan	-	-	-	-
Australia/New Zealand	-	-	20	20
United States	-	15	20	20
Canada	15	15	15	15
OECD Europe	15	15	20	20
Former CP Europe	10	15	20	20
Middle East	-	-	-	-
Total	10.2	15	20	20

Yield levels: In 2025 all regions with bioenergy plantations, except United States and OECD Europe, are assumed to have a yield level at 10 dry Mg per hectare and year. For United States and OECD Europe the yield level is assumed to be 15 dry Mg per hectare and year. In 2050, all regions with bioenergy plantations, except Canada, have reached the yield level 15 dry Mg per hectare and year. Yield levels in Canada is 10 dry Mg per hectare and year in 2050. In 2075 and 2100 all regions except Canada have a yield level at 20 dry Mg per hectare and year.

No reference is given in order to justify the assumptions about yield levels. However, since LESS-BI is a modification and extension of the RIGES, the HALL assessment (Hall, *et al.* 1993) serves as an implicit basis for the assumption also in LESS-BI (see the overview of the HALL assessment included in this appendix).

Area dedicated to energy crops: It is assumed that in industrialized countries, bioenergy plantations are located primarily on excess agricultural lands. Bioenergy feedstock production and conversion to high-value energy carriers is suggested a possibility to phase out agricultural subsidies.

For developing countries, it is assumed that bioenergy plantations are located primarily on deforested or otherwise degraded lands that are not needed for food production. For Africa and Latin America, the authors refer to (Grainger 1988, Houghton 1990) regarding extent of degraded land in developing countries. Reference is also given to (Larson, *et al.* 1995) who performs a country-by-country assessment of the potential for growing biomass for energy in Africa, Asia and Latin America, taking into account population growth and increased food requirements.

Residues: Biomass energy supplies from residues and urban refuse is given in tables B11.3-B11.4 below.

South and East Asia supplies significant amounts of biomass energy in the form of residues thanks to it's large population, especially after 2050 when also developing regions are assumed to use urban refuse for bioenergy. Latin America also supply large amounts of residue biomass, thanks to high per capita dung and sugarcane residue generation rates and a fairly large population. After 2050, Africa supply almost as much total residues as Latin America, thanks to the combination of higher population and consideration of urban refuse.

Australia/New Zealand have very high per capita agricultural residue generation rates, and Canada have very high per capita residue generation rates related to cereals and industrial round wood production. However, since the populations in Australia/New Zealand and Canada are relatively small, this has no large impact on the global totals.

Table B11.3: Biomass supplies from forests for the LESS-BI (EJ)

	Forest residues				Fuelwood
	2025	2050	2075	2100	All years
Africa	0.72	0.97	1.12	1.17	0.78
Latin America	0.87	1.01	1.06	1.08	0.51
South and East Asia	0.95	1.12	1.2	1.23	1
Centrally Planned Asia	0.78	0.84	0.87	0.9	0.39
Japan	0.2	0.2	0.2	0.2	0
Australia/New Zealand	0.15	0.15	0.15	0.15	0
United States	2.18	2.15	2.13	2.14	0.2
Canada	0.96	0.95	0.95	0.95	0.01
OECD Europe	1.28	1.27	1.26	1.27	0.1
Former CP Europe	2.18	2.27	2.34	2.38	0.19
Middle East	0.18	0.23	0.26	0.27	0
Total	10.45	11.17	11.53	11.73	3.19

Table B11.4: Biomass supplies from sugarcane and cereals for the LESS-BI (EJ)

	sugarcane				cereals			
	2025	2050	2075	2100	2025	2050	2075	2100
Africa	1.2	1.67	1.92	2.01	0.68	0.85	0.9	0.87
Latin America	5.18	6.17	6.47	6.61	0.98	1.7	2.7	3.99
South and East Asia	3.11	3.79	4.03	4.14	2.35	2.98	3.32	3.53
Centrally Planned Asia	0.63	0.35	0.35	0.35	1.14	1.19	1.05	0.83
Japan	0	0	0	0	0.16	0.23	0.23	0.23
Australia/New Zealand	0.18	0.18	0.18	0.18	0.27	0.38	0.46	0.51
United States	0	0	0	0	1.73	1.81	1.57	1.23
Canada	0	0	0	0	0.35	0.35	0.3	0.23
OECD Europe	0	0	0	0	1.42	1.41	1.19	0.91
Former CP Europe	0	0	0	0	1.82	2.07	1.95	1.64
Middle East	0	0	0	0	0	0	0	0
Total	10.3	12.2	13	13.3	10.9	13	13.7	14

Table B11.5: Biomass supplies from dung and urban refuse for the LESS-BI (EJ)

	dung				urban refuse			
	2025	2050	2075	2100	2025	2050	2075	2100
Africa	1.73	2.6	3.36	4.17	0	0	6.68	6.97
Latin America	1.62	2.09	2.31	2.36	0	0	2.49	2.54
South and East Asia	3.06	5.77	8.25	10.8	0	0	9.13	9.38
Centrally Planned Asia	0.62	0.7	0.66	0.59	0	0	5.49	5.7
Japan	0	0	0	0	0.53	0.53	0.52	0.53
Australia/New Zealand	0.24	0.31	0.35	0.36	0.06	0.06	0.06	0.06
United States	0.31	0.21	0.11	0.06	1.14	1.12	1.12	1.12
Canada	0	0	0	0	0.11	0.11	0.11	0.11
OECD Europe	0.38	0.4	0.33	0.25	1.3	1.29	1.28	1.29
Former CP Europe	0.55	0.57	0.47	0.36	0	0	1.53	1.56
Middle East	0	0	0	0	0	0	1.14	1.18
Total	8.5	12.6	15.8	18.9	3.1	3.1	29.6	30.4

Forest residues: Residues associated with both industrial round wood production and round wood production for fuel wood and charcoal is assumed to be available for modern biofuel production. Industrial round wood production increases with population. Future round wood production for fuel wood and charcoal is assumed to be 75 percent of the 1985 level, as reported by (FAO 1986).

The basis is not clearly presented, but it is likely that the assumptions are the same as in the RIGES:

For all regions, residues generation are related to both industrial round wood production and round wood production for fuelwood and charcoal, using coefficients derived for the U.S. forest sector in the late 1970s:

-felling residues amounts to 39 percentage of felled timber
-wood processing residues amounts to 45 percent of industrial round wood

50 percent of the forest residues and 75 percent of wood processing residues are assumed to be available for energy purposes. This results in forest residues generation rates of:

0.65 times industrial round wood production
0.32 times round wood produced for fuelwood and charcoal

Agricultural residues: Agricultural residues accounted for in LESS-BI are sugarcane residues, cereal residues, and animal dung. Sugarcane production is assumed to increase in proportion to the population. Cereal production levels are assumed to be those projected by the IPCC Response Strategies Working Group (IPCC 1990). Dung production is assumed to increase in proportion to meat production in all regions except South and East Asia and OECD Europe, where dung production increase in proportion to production of dairy products, as projected by (IPCC 1990).

Sugarcane residue generation is assumed to be 150 dry kg of bagasse (2.85 GJ) plus 279 dry kg of tops and leaves (5.30 GJ) per Mg cane. All the bagasse and two thirds of tops and leaves are available for energy purposes. It is not clear how sugarcane in CP Asia is treated. IN 2025 the LESS-BI is slightly less than double the 2050-2100 level, and the RIGES 2025-2050 level.

Cereal residues generation is assumed to be 1.3 times cereal production (weight basis). 25 percent of the residues are assumed to be available for energy purposes (heating value=12 GJ/Mg).

Dung production is estimated based livestock inventories (FAO 1986), together with dung production coefficients and dung heating values reported for different animals by (Taylor, *et al.* 1982). It is assumed that 1/8 of the produced dung is recoverable.

Municipal waste: The use of urban refuse for energy is considered only for industrialized countries up to 2050. After 2050, also developing countries are considered. They are assumed to have the same residue generation rate as OECD Europe. It is assumed that the production rate per capita is constant, and that 75 percent of the produced urban refuse is available for energy purposes.

United States and Canada have an annual generation rate of 330 kg per capita (15.9 MJ/kg). Japan, Australia/New Zealand and OECD Europe (and developing countries after 2050) have an annual generation rate of 300 kg per capita (12.7 MJ/kg).

Traditional bioenergy: It is assumed that in the period 2025 to 2100 wood from the natural forest is no longer used for traditional fuel wood and charcoal applications (e.g., cooking), but is instead used to produce electricity or modern fuels. Roundwood production for such modern energy uses is set to 75 percentage of the 1985 level of round wood production for traditional fuelwood and charcoal applications, as reported by FAO (1986).

Round wood production for traditional fuel wood and charcoal applications is assumed to generate forest residues to the same extent as industrial round wood production, and half of this is accounted for as forest residues. Therefore, the *total* amount of wood made available for modern energy uses via transformation of traditional round wood production is 99 percentage of the 1985 level of such activities.

Additional

As noted in the section about traditional bioenergy above, round wood production for traditional fuel wood and charcoal uses is assumed to be available for modern energy uses. Table B11.6 gives the round wood production for modern energy uses in the RIGES. Industrial round wood production, which is constant over the scenario period when expressed on a per capita basis, is included as a comparison. As can be seen, developing regions are expected to use more, or similar amounts of round wood for modern bioenergy as for regular forest products such as sawn wood, panels and paper. In industrialized countries on the other hand, industrial round wood production is much larger than round wood production for modern bioenergy. This is a direct consequence of the assumption that traditional bioenergy (which is the dominating use of wood in developing countries today) will be phased out, and the resource base will instead be available for modern energy uses.

Table B11.6: Round wood production for bioenergy and industrial round wood in LESS-BI

	Round wood for bioenergy					Industrial round wood[viii]
	(EJ)	(GJ/capita)				(GJ/capita)
	All years	2025	2050	2075	2100	All years
Africa	2.4	1.6	1.2	1.0	1.0	0.7
Latin America	1.6	2.2	1.9	1.8	1.8	1.9
South and East Asia	3.1	1.2	1.0	1.0	1.0	0.6
Centrally Planned Asia	1.2	0.7	0.7	0.6	0.6	0.7
Japan	0	0	0	0	0	2.2
Australia/New Zealand	0	0.9	0.9	0.9	0.9	10.5
United States	0.6	2.1	2.2	2.2	2.2	11.6
Canada	0	1.0	1.1	1.1	1.1	50.9
OECD Europe	0.3	0.7	0.7	0.7	0.7	4.3
Former CP Europe	0.6	1.2	1.1	1.1	1.1	6.7
Middle East	0	0.1	0.1	0.1	0.0	1.0
Total	10.0	1.2	1.0	1.0	1.0	2.0

Conversion technologies included: Regional production of biomass-derived fuels and electricity in LESS-BI year 2050 is given in table B1.12 below. Most biomass is used for electricity generation and for fluid fuels production (especially methanol[14] and hydrogen, produced thermochemically).

It is assumed that advanced biomass-integrated gasifier/gas turbine (BIG/GT) power cycles with efficiencies of 43 percent become the norm by 2025, and biomass-integrated gasifier/fuel cell (BIG/FC) technologies with efficiencies of 57 percent become the norm by 2050. Efficiencies in methanol and hydrogen production have not been found in the LESS-BI report. In the RIGES, methanol and hydrogen are produced at efficiencies of 62 and 70 percent in 2025, and 63 and 72 percent in 2050 respectively. These values can be taken as indicative of efficiency assumptions in LESS-BI.

Table B11.7: Regional production of the dominant biomass-derived fuels and electricity in LESS-BI year 2050 and 2100

	Electricity (TWh/yr)		Methanol (EJ/yr)		Hydrogen (EJ/yr)	
	2050	2100	2050	2100	2050	2100
Africa	614	1173	6.42	22.85	3.30	4.82
Latin America	1394	1665	18.09	28.70	12.38	11.21
South and East Asia	450	3733	0	0	5.43	4.82
Centrally Planned Asia	716	2215	0	0	0.49	0.49
Japan	0	0	0.55	0	0	0
Australia/New Zealand	22	25	0.35	5.09	0	0
United States	504	402	5.76	8.74	3.40	5.00
Canada	0	0	1.48	2.28	0.75	0.75
OECD Europe	399	399	2.62	4.44	4.31	4.31
Former CP Europe	1355	1782	2.29	6.50	2.94	8.30
Middle East	0	0	0.15	0.84	0	0
Total	5453	11394	37.71	79.44	33.00	39.70

Cost estimates: The energy demand and mix of primary energy supply is not generated via energy-economy modelling. Instead, the energy demand is taken from (IPCC 1991), and the scenario is then constructed based on the assumption that low CO2-emitting technologies will be included if costs for energy services provided by that technology is comparable to the costs of energy services based on advanced conventional energy technologies.

Results:

Total biomass supplies for energy for the LESS-BI is given in tables B11.8 and B11.9 below. Both liquid and gaseous fuels are traded. Africa and Latin America increase their methanol export over the scenario period, with biomass gradually substituting for natural gas as feedstock in methanol production.

[14] Methanol is emphasized in the scenario because it is especially well suited for use with fuel-cell vehicles, which is assumed to become the technology of choice for road transportation in the period 2025 to 2050. However, it is acknowledged that also ethanol derived from cellulosic biomass feedstocks via enzymatic hydrolysis is a promising liquid biofuel.

Also Australia/New Zealand and to some extent Canada export methanol, but Africa and Latin America dominates with approximately 84 percent of total exports in 2100 (above 40 percent each). S&E Asia stands out as the dominating importer taking 83 percent of the methanol that is traded between regions.

Hydrogen is traded to a smaller extent, with Africa as the only exporter that has significant hydrogen production based on biomass.

Since residues and forest fuels show identical growth in LESS-BI and RIGES, the slower development of total bioenergy in the beginning of the scenario period takes the form of lower establishment rate of plantations. Consequently, in the near term the relative importance of residues is larger in LESS-BI. In all regions with plantations, except South and East Asia, plantations dominate from 2050 to 2100.

With the exception of the market difference in the growth rate of plantations, and that South and East Asia have plantations in LESS-BI, the regional characteristics in LESS-BI are similar to the RIGES. Details on regional residue generation rates can be found in tables B11.10-B11.11 in this appendix.

Table B11.8: Primary energy supply from forest round wood and residues (EJ)

	Forests[ix]	Residues[x]			
	All years	2025	2050	2075	2100
Africa	2.4	5.1	6.9	14.8	16.0
Latin America	1.6	9.2	11.5	15.5	17.1
South and East Asia	3.1	10.5	14.7	26.9	30.1
Centrally Planned Asia	1.2	3.6	3.5	8.8	8.8
Japan	0.0	0.9	1.0	1.0	1.0
Australia/New Zealand	0.0	0.9	1.1	1.2	1.3
United States	0.6	5.6	5.5	5.1	4.8
Canada	0.0	1.4	1.4	1.4	1.3
OECD Europe	0.3	4.5	4.5	4.2	3.8
Former CP Europe	0.6	4.7	5.1	6.5	6.1
Middle East	0.0	0.2	0.2	1.4	1.5
Total	10.0	46.4	55.3	86.8	91.5

Table B11.9 Primary energy supply from plantations, and total supply from all biomass sources (EJ)

	Plantations				Total			
	2025	2050	2075	2100	2025	2050	2075	2100
Africa	4.9	14.2	37.6	45.5	12.5	23.5	54.8	63.9
Latin America	6.4	50.2	54.8	63.9	17.2	63.3	71.9	82.6
South and East Asia	1	5.1	9.4	21.4	14.6	22.9	39.5	54.6
Centrally Planned Asia	1.2	8.5	20	20.6	6.0	13.2	30.0	30.6
Japan	0	0	0	0	0.9	1.0	1.0	1.0
Australia/New Zealand	0	0	2.2	8.1	0.9	1.1	3.4	9.4
United States	0	12.6	18.2	21.9	6.2	18.7	24.0	27.3
Canada	0.3	2.3	3.2	3.8	1.8	3.8	4.6	5.1
OECD Europe	2.2	9.5	12.6	13.1	7.0	14.3	17.1	17.2
Former CP Europe	1.2	12	25.4	29.2	6.5	17.7	32.5	35.9
Middle East	0	0	0	0	0.2	0.3	1.4	1.5
Total	17.3	114.4	183.5	227.5	73.7	179.6	280.3	329.0

Table B11:10: Primary energy supply from forest round wood and residues (GJ/cap)

	Forests[xi]				Residues[xii]			
	2025	2050	2075	2100	2025	2050	2075	2100
Africa	1.6	1.2	1.0	1.0	3.4	3.4	6.3	6.6
Latin America	2.2	1.9	1.8	1.8	12.8	13.8	17.9	19.2
South and East Asia	1.2	1.0	1.0	1.0	4.1	4.9	8.4	9.2
Centrally Planned Asia	0.7	0.7	0.6	0.6	2.1	1.9	4.6	4.4
Japan					6.4	7.0	6.9	7.0
Australia/New Zealand	0.9	0.9	0.9	0.9	40.9	49.1	54.5	57.8
United States	2.1	2.2	2.2	2.2	19.2	19.3	18.1	16.7
Canada	1.0	1.1	1.1	1.1	49.3	50.7	48.9	46.1
OECD Europe	0.7	0.7	0.7	0.7	9.9	10.0	9.3	8.5
Former CP Europe	1.2	1.1	1.1	1.1	9.5	9.8	12.1	11.2
Middle East	0.1	0.1	0.1	0.05	0.6	0.6	3.5	3.5
Total	1.2	1.0	1.0	1.0	5.7	5.8	8.5	8.7

Table B11.11: Primary energy supply from plantations, and total supply from all biomass sources (GJ/cap)

	Plantations				Total			
	2025	2050	2075	2100	2025	2050	2075	2100
Africa	3.3	7.0	16.1	18.7	8.3	11.6	23.5	26.2
Latin America	9.0	60.6	63.1	72.0	24.0	76.3	82.8	93.0
South and East Asia	0.4	1.7	2.9	6.5	5.8	7.6	12.4	16.6
Centrally Planned Asia	0.7	4.6	10.4	10.3	3.5	7.1	15.6	15.3
Japan	0.0	0.0	0.0	0.0	6.4	7.0	6.9	7.0
Australia/New Zealand	0.0	0.0	100.0	371.6	41.8	50.0	155.5	430.3
United States	0.0	44.2	64.3	77.1	21.4	65.6	84.6	96.0
Canada	10.3	82.1	114.3	134.7	60.7	133.9	164.3	181.9
OECD Europe	4.8	21.2	28.2	29.2	15.4	31.8	38.2	38.4
Former CP Europe	2.4	23.0	47.4	53.6	13.1	34.0	60.6	65.9
Middle East	0.0	0.0	0.0	0.0	0.7	0.7	3.6	3.6
Total	2.1	12.0	18.0	21.7	9.0	18.9	27.6	31.4

B12. Name: GBP2050

(Fischer and Schrattenholzer 2000)

Timeframe: 1990 – 12050

Geographical aggregation: World, 11 regions

AFR: Sub-Saharan Africa
CPA: Centrally Planned Asia and China
EEU: Central and Eastern Europe
FSU: Newly independent states of the former Soviet Union
LAM: Latin America and the Caribbean
MEA: Middle East and North Africa
NAM: North America
PAO: Pacific OECD
PAS: Other Pacific Asia
SAS: South Asia
WEU: Western Europe

Background: The study on the bioenergy potentials through 2050 is constructed by the International Institute for Applied Systems Analysis (IIASA) in Austria. The estimated bioenergy potentials are consistent with scenarios of agricultural production and land use developed at the IIASA. It was stated that the potentials of renewable energy ca be theoretically, technical, or economic. The estimation reported in this study were mentioned to take into account economic criteria, and allow for the possibility of gradually changing economic conditions in the future. The estimations exclude the bioenergy potential of the hydrosphere, (in particular the oceans might have large potentials).

Driving Forces:

As a starting point, the land-use changes for each of the eleven regions between 1990 and 2050 were assumed. This was done by following IIASA's Basic Linked System of Models, a business-as-usual (BLS-BAU) global agricultural scenario of overall economic and agricultural development. That scenario includes the quantification of food supply and demand of a world population.

Population: It was assumed that 5.3 billion in 1990 to over 10 billion in 2050.

Economic: Direct assumptions regarding economic growth were not mentioned.

Land: The balance of additional food supply comes from increased production per hectare of arable land, which is grown at an average annual rate of 1.1%

Types of biomass sources included

The estimation includes five types of biomass: crop residues; bioenergy from grassland, bioenergy from sustainable use of forest products, animal waste and municipal waste.

Energy crops: The use of energy crops was assumed to be on grassland.

Yield: The bioenergy potential from grassland was assumed to grow at rates comparable to agricultural productivity (1%/yr). To reflect the uncertainty behind this assumption, high and low annual growth rates were assumed (0.8% and 1.25%). The yields obtained were assumed to differ among regions (see Table B12.1 and Table B12.2).

Table B12.1: assumed energy crop production (low estimate) in GJ/ha/yr)

Energy crops from grasslands (low)	1990	2000	2010	2020	2030	2040	2050
AFR	52	56	60	64	69	73	79
CPA	33	36	38	41	44	47	50
EEU	128	138	148	159	171	182	194
FSU	31	33	36	38	41	44	47
LAM	73	78	84	90	96	103	110
MEA	40	42	45	49	52	56	60
NAM	53	57	61	66	70	75	80
PAO	25	27	29	31	33	36	38
PAS	111	119	128	137	146	157	167
SAS	70	75	81	87	93	99	106
WEU	67	72	77	83	89	95	101
average world	62.1	66.6	71.5	76.8	82.2	87.9	93.8

Table B12.2: assumed energy crop production (high estimate) in GJ/ha/yr)

Energy crops from grasslands (high)	1990	2000	2010	2020	2030	2040	2050
AFR	52	58	65	72	80	89	99
CPA	33	37	41	46	51	57	63
EEU	128	145	164	184	205	226	248
FSU	31	35	39	43	48	53	59
LAM	73	81	91	101	113	125	139
MEA	40	44	49	55	61	68	75
NAM	53	60	67	74	83	92	102
PAO	25	28	31	35	39	43	48
PAS	111	124	139	155	172	191	212
SAS	70	79	88	98	109	121	134
WEU	67	75	84	94	104	116	128
average world	62.1	69.6	78.0	87.0	96.8	107.4	118.8

Land availability: The land availability is assessed by using IIASA's Basic Linked System of Models, however, the exact figures were not given.

Residues: The bioenergy potential of crop residues is calculated separately for five crop groups: wheat, rice, other grains, protein feed, and other food crops. For each, a residue factor determines the ration between total above ground biomass and the primary food produce. In a second step, an "availability fraction" determines those parts of the residues that are considered potentially available for energy use. The exact assumptions were not given. The calculated yield rates for each of the eleven regions are summarized in Table B12.3.

Table B12.3: Assumed crop residues from cultivated land in GJ/ha/yr

	1990	2000	2010	2020	2030	2040	2050
Crop residues from cultivated land							
AFR	6.6	8.2	9.4	10.6	11.8	13.4	14.8
CPA	23.9	27.6	30.5	33.6	35	36.6	37.9
EEU	14.6	15.3	15.7	16.5	16.6	17.9	18.4
FSU	9.1	9.3	9.6	10.1	10.1	10.9	11.2
LAM	9.7	11.3	13	14.5	15.6	16.9	17.8
MEA	12	15.2	18.3	21.7	23.9	27.1	29
NAM	16.2	17.4	18.5	19.9	20.4	21.2	21
PAO	5.2	6.2	7.1	8	8.6	9.8	10.8
PAS	10.2	12.6	14.8	17	19.1	20.8	22.1
SAS	17.4	19.6	20.7	21.3	22.8	25.2	26.9
WEU	14.4	15.8	16.8	18	18.8	20.3	21.5
average world	12.7	14.4	15.9	17.4	18.4	20.0	21.0

Sustainable use of forest products: The bioenergy potential of forest products in 1990 is based on DESSUS. The assumed average annual growth rates were assumed at two levels: low: 0.8% annual growth. High: 1.25% annual growth. No exact numbers were given. Table B12.4 and B12.5 shows the assumed potential in GJ/ha/yr for sustainable forest products (low and high estimate).

Table B12.4: assumed sustainable forest products in GJ/ha/yr (low estimate)

Wood from forests and forest products (low)	1990	2000	2010	2020	2030	2040	2050
AFR	17	18	20	21	23	24	26
CPA	27	29	31	33	35	38	40
EEU	19	21	22	24	26	28	29
FSU	11	11	12	13	14	15	16
LAM	13	14	15	16	17	18	20
MEA	12	12	13	14	15	16	17
NAM	15	16	17	18	20	21	22
PAO	18	19	20	22	23	25	27
PAS	19	21	22	24	25	27	29
SAS	56	60	64	68	73	78	84
WEU	15	16	17	18	20	21	22
average world	20.2	21.5	23.0	24.6	26.5	28.3	30.2

Table B12.5: assumed sustainable forest products in GJ/ha/yr (high estimate)

Wood from forests and forest products (high)	1990	2000	2010	2020	2030	2040	2050
AFR	17	19	21	24	27	29	33
CPA	27	30	33	37	41	46	51
EEU	19	22	24	27	30	34	37
FSU	11	12	13	15	16	18	20
LAM	13	15	16	18	20	22	25
MEA	12	13	14	16	18	20	22
NAM	15	17	18	21	23	25	28
PAO	18	20	22	25	28	31	34
PAS	19	22	24	27	30	33	37
SAS	56	62	69	77	86	96	106
WEU	15	17	18	21	23	25	28
average world	20.2	22.6	24.7	28.0	31.1	34.5	38.3

Animal waste: The estimation of the bioenergy potential of animal waste is based on animal feed requirements in the BLS-BAU scenario. These feed requirements are supplied from crops to the extent specified by the BLS model. The balance is then subtracted from the bioenergy potentials of crop residues and grassland yields as calculated above to avoid double counting. Of all animal feed inputs, "digestible energy" is subtracted, and the rest defines the bioenergy potential of animal waste.

Municipal waste: The method for estimating the primary energy potential of municipal waste was the same as in the IIASA-WEC study. There it was assumed that with increasing wealth, per-capita municipal waste asymptotically reaches approximately 2.5 tonne of waste. This amount is equivalent to 10 TJ per year.

Results:

As the total bioenergy potential of the base year, 1990, 225 EJ was estimated. By the year 2050, this potential was estimated to grow to between 370 and 450 EJ. The slowest growth occurred in the "crop residues" category. This was explained by assuming the much faster increasing yields of crops aim mainly increasing their harvesting index.

B13. Name: IMAGE SRES-B1 and A1
B1 scenario: (De Vries, J. Bollen et al. 2000)
A1 scenario:(IPCC 2000)

Timeframe: 1970-2100

Geographical aggregation: World, 13 regions

Table B13.1. The 13 world regions distinguished in the IMAGE model.

Canada	Middle East
USA	South Asia
Latin America	China+CP Asia
Africa	East Asia
OECD Europe	Oceania
Eastern Europe	Japan
former Soviet Union	

Background: This scenario calculation is part of the contribution of the WorldScan-model developed at the Dutch Central Plan Bureau (CPB) and the IMAGE model developed at the Dutch National Institute of Public Health and the Environment (RIVM) to the Special Report on Emission Scenarios of the Intergovernmental Panel on Climate Change (IPCC). In the context of SRES the scenarios are divided into 4 scenario families, i.e. A1, A2, B1 and B2. All scenarios describe future worlds without specific policies aimed at solving the climate-change problem. The families are characterized by differences in the effectiveness of governance and the degree of citizen's social and environmental concerns. The governance has been linked to globalization trends (trade liberalization, market-based mechanisms and instruments, the size of interregional capital flows and the dissemination of technical innovations). Social and environmental concerns have been related to, for instance, the degree of support for solidarity between the rich and the poor, "green" lifestyles and technologies, and community-oriented experiments toward a more sustainable world.

Driving forces/scenario:

The A1 scenario: Present trends of globalization and liberalization continue. This and rapid technological innovations lead to high economic growth. Affluence converges rapidly but the absolute difference between developed and less developed world regions keeps growing. Increasing affluence supports rapid decline in fertility levels and world population drops after 2050. Life expectancy increases and aging becomes an important phenomenon.

The B1 scenario: Present trends of globalization and liberalization continue, but there is a strong commitment towards sustainable development. Because business takes an active role, the pace of technological innovation is high. Increasing and more equally distributed affluence, supported by policies oriented towards education for women and community-based initiatives cause a rapid decline in fertility levels: world population drops after 2050. Affluence converges among the world regions at a faster rate than in the A1 scenario.

Population and economic growth: IPCC prescribed scenarios were used for population for 4 world regions and the world GDP (see Table B13.2). These scenarios were translated into the regional break-up of the IMAGE model.

Energy demand: Sector activity levels are used to calculate demand for energy services. This demand is translated in final and primary energy use, taking into account efficiency improvements, cost-decreasing innovations in energy supply, price changes and fuel depletion. High economic growth leads to increasing energy use in the first half of the 21st Century. In A1 total energy primary consumption increases to about 1200EJ per year in 2050 as a result of the high economic growth rates. In B1 energy consumption increases to only 800 EJ in 2050. In the second half of the 21st Century energy demand in both scenarios starts to decline as a result of declining global population and ongoing efficiency improvement.

Types of biomass included

- Traditional biofuels, not requiring land resources. Hence this category includes fuelwood harvested from forests not planted with the purpose of biofuel production, and dung, by-products, residues).
- Modern biofuels, including annual crops (sugarcane, maize) and perennial crops (non-woody and woody biofuel crops).

Biofuel demand: Briefly, demand for biofuels is modelled as follows: bioliquid fuels based on sugar competes with fossil-energy based fuels in the transport sector, while in the electricity sector biofuels compete with primarily natural gas. In both scenarios prices of fossil fuels increase as a result of gradual depletion of resources. Prices of biofuels decrease as a result of technological innovations, both in the efficiency and the productivity of the crops. If production of biofuels per region approaches maximum potential production taken from (Hall, Rosillo-Calle et al. 1993), their price starts to increase reflecting competition with other land uses and the use of less productive land. All regions can trade biofuels to fulfill their needs. The resulting penetration of biofuels as a fraction of total energy use is higher in B1 than in A1. Total biofuel use is highest in A1.

Yields: For woody and non-woody perennial crops the productivity functions given by (Kassam, H.T. van Velthuizen et al. 1991) were used. Non-woody biofuel crops include a variety of grass species. Woody biomass includes several fuel wood species.

For modelling yields of sugarcane and maize the agro-ecological zones approach of FAO (FAO 1981) as described and implemented by (Leemans and Solomon 1993) and (Leemans and Van den Born 1994) was used.

These productivity models allow for the simulation of responses to climatic change and enhanced atmospheric CO_2 concentration (CO_2 fertilizing effect) and climate. A changing climate will change both the potential distribution of crops and their productivity. Yields under the IMAGE SRES A1 and B1 scenarios are in Table B13.2.

Land cover changes: The land cover model of IMAGE simulates changes in land cover by reconciling demands for land use with the potential of land. This is done by changing land cover on a terrestrial grid (0.5^{o} latitude and 0.5^{o} longitude) until regional demands for land use are satisfied. The allocation is based on a number of simple rules (Alcamo, E. Kreileman et al. 1998)

The principal rules for agricultural expansion include minimal distance to agricultural land and densely populated areas, and large rivers and other water bodies. A second criterion is the potential productivity. The best land is used first.

In case of competition between food and animal feed production on the one hand and biofuel production on the other hand, the demand for modern biofuels (see above and Table B13.2) is, within the limits of available land and its productivity, always met in the IMAGE model. The reasoning behind this is that biofuel crops will command high prices, and will therefore out-compete demands for timber and food. Hence, if not all biofuel demands are met, the model will reallocate agricultural land for biofuel crops, and this has consequences for either the human diet, with for example a change from animal products with high land demand to plant products.

Table B13.2. World aggregates of yields, total area planted and total energy production from biofuel crops.

A1 scenario	1990	2000	2025	2050	2100
Population (million)	5280	6122	7908	8708	7047
GDP (trillion US$)	21	26.7	68.6	163.5	518.8
Annual production (ton d.m./ha)	15.6	21.7	22.6	21.5	23.9
Annual production (MJ/ha)	164	228	237	226	251
Total area (Mha)	7.7	9.7	125.4	373.5	333.6
Total energy (EJ/yr)	2	2	36	105	107
B1 scenario	1990	2000	2025	2050	2100
Population (million)	5280	6122	7908	8708	7047
GDP (trillion US$)	21	26.8	62.9	135.6	328.4
Annual production (ton d.m./ha)	15.6	21.6	22.5	22.1	23.7
Annual production (MJ/ha)	164	227	236	232	249
Total area (Mha)	7.7	9.6	99.3	268.0	194.3
Total energy (EJ/yr)	2	2	28	78	62

B14. Name: DESSUS
(Dessus, Devin et al. 1991)

Timeframe: 1990-2020

Geographic aggregation: world; 22 regions

Background: Dessus at al. included in their study on the renewable energy potential, ten principal technologies of global interest. Among them four technologies related to biomass energy: Energy from wood; energy from urban waste; energy from rural waste and biomass energy crops. It was stated that the basic data on urban waste was taken from knowledge on urban population and mean per capita annual waste The basic data on wood and biomass energy crops were taken from the FAO, respectively the yearbook of forest products and the yearbook of agricultural products were used. The basic data on urban waste were taken from

Driving forces:
Dessus et al have not used a scenario approached. Driving forces on population and economics are not explicitly made.

Types of biomass included

As mentioned above, Dessus et al. included four types of biomass energy technologies in their study.

Energy from wood: This includes harvesting of the renewable part of existing forestry: direct wood logs, wood briquets and pellets, charcoal or wood gas burning. Energy from wood is distinguished between commercial and non-commercial wood. This distinction is based on the efficiency of the use of the wood.
The reserves of energy from wood is determined as area multiplied by the yield (8 Mg/ha/yr for rain tropical forest, 1.5 for dry tropical forest, 1 for savanna, 3 for temperate forest and 2 for taiga) the share of the wood that is not in competition with raw materials (wood pulp, timber etc.), which varies between 50 % for the industrialized regions and 70% for developing regions. The accessibility, the share of wood that is actually accessible varies largely among the regions, from 80% in European regions to 25% in Latin America.

Energy from urban waste: The reserves of energy from urban waste per capita were assumed to depend on the family size and development degree: 0.3 ton per capita for regions where mean family size is <3.5 people, 0.1 ton for 3.5 top 5 people and 0.05 ton for regions with a mean family size over 5 people.

Energy from rural waste includes agricultural and animal waste.
Waste reserves are derived from production data of each main agricultural product. Table B14.1 shows the assumed accessibility of the residues and yield of various crops.

B14.1: The assumed accessibility of the residues and yield of various crops

	Waste/grain mean ratio	Access ratio (%)	Workable productivity (toe/ton)
Wheat	0.8	30 - 50	0.10 – 0.15
Cereals	1	30 - 50	0.12 – 0.17
Ind. Corn	1.2	30	0.15
Rice	2	30 - 50	0.2 – 0.24
Sugar cane	3	50 – 60	0.07 – 0.08
Grape		60	0.1
Bovines		30	0.08
Ovins		30	0.01
Swine		30	0.02

The amount of biomass energy crops is assumed to depend on the number of inhabitants per cultivated hectare. The maximum ratio "r" of usable land on cultivated land has been taken as r = 10% - d/100 where d is the density of population by cultivated area. This gives the opportunity to plant a maximum of 10% of the cultivated land in areas where density is low. It was assumed that from this resource 30 to 40% are accessible for industrial countries and 30% for developing countries, except Brazil because it is already engaged in a big ethanol program. Table B14.2 shows the assumed productivity. Table B14.2 summarizes the assumptions regarding the four types of biomass.

Table B14.2 Assumed productivity by DESSUS

	Productivity (tons/ha)	Productivity (toe/ton)	Workable productivity (toe/ha)
Short rotation bushes	7 – 10	0.44	3 – 4.4
Sugar cane	40 - 70	0.065	2.6 – 4.5

Table B14.3 summarizes the assumption regarding the four types of biomass.

	Energy from wood		Urban waste		Rural waste	Biomass energy crops	
	Access ration	Annual reserves (Mtoe)	Waste per capita (tons)	Annual reserves (Mtoe)	Annual reserves	Short rotation bushes (Mtoe)	Sugarcane (Mtoe)
Canada	65	114	0.3	0.5	7.2	3.3	0
United States	75	100	0.3	5.3	53.7	8.8	1.6
EEC Europe	80	24	0.3	7.7	32.4	3.5	0
Northern Europe	80	26	0.3	0.6	1.4	0.7	0
Central Europe	80	11	0.3	2.2	14	2.2	0
Soviet Union	55	216	0.3	5.4	35.3	13.2	0
Japan	70	11	0.3	2.7	4.2	0	0
Australia & N Zealand	50	5	0.3	0.5	9.5	1.5	0.9
Mexico	35	28	0.05	0.3	9.1	1.3	0.3
Brazil	25	280	0.1	1	36.7	2.2	8
Latin America	25	176	0.1	1.1	16.1	3.3	0.6
Southern Europe	70	5	0.1	0.4	6.4	1.1	0
Middle East	80	6	0.05	0.3	2.7	0.6	0
Northern Africa	80	16	0.05	0.3	2.6	0.3	0
Nigeria Gabon	50	23	0.05	0.3	2.4	0.9	0
Africa	35	247	0.05	0.3	17.7	3	0
South Africa	80	1	0.1	0.2	4.2	0.8	0.7
India	80	87	0.1	1.9	67.8	2	3.2
China	75	85	0.1	3.4	80	2.2	1
South Korea	80	6	0.1	0.5	2.7	0	0
Indonesia	30	101	0.1	0.4	12.7	0.4	0
Asia Oceania	35	142	0.1	1.4	46.4	1.7	0.7
World		1710		38	466	53	17

Economy: Regarding energy from wood it was assumed that competition could occur in regions near forest areas (distance < 200 km)
Energy from urban waste was assumed to be competitive for population densities > 10000 inhabitants
Energy from rural waste was assumed to be competitive when de-pollution is necessary (if large batteries of cattle are involved)
The biomass energy from energy crops is assumed to be competitive with fossil fuels in areas where the productivity of energy crops is better than 4 toe per hectare for wood and better than 3 toe for sugar cane.

Results:

Results are shown in Table B14.4.

B14.4: Results from DESSUS

	wood (comm)	wood (non comm)	energy crops	waste	Total
World	64.9	21.0	14.7	26.0	126.5
North America	9.5	0.0	3.4	2.9	15.8
Europe	2.5	0.0	2.7	2.4	7.6
Japan, Australia, NZ	1.0	0.0	0.5	0.7	2.1
USSR Central Europe	10.5	0.0	1.4	2.6	14.5
Latin America	21.0	5.0	2.9	3.6	32.5
N Africa Middle East	0.8	0.2	0.4	0.7	2.2
Africa	10.1	5.9	2.5	2.2	20.6
India	1.7	2.3	0.2	3.8	8.0
China	1.7	2.1	0.2	3.8	7.8
Asia Oceania	6.3	5.4	0.4	3.4	15.5

B15. Name: Global Energy Perspectives

(Grübler, Jefferson et al. 1995)

Timeframe: 1990 - 250

Geographical aggregation: world; 11 regions

AFR: Sub-Saharan Africa
CPA: Centrally Planned Asia and China
EEU: Central and Eastern Europe
FSU: Newly independent states of the former Soviet Union
LAM: Latin America and the Caribbean
MEA: Middle East and North Africa
NAM: North America
PAO: Pacific OECD
PAS: Other Pacific Asia
SAS: South Asia
WEU: Western Europe

Background: The report on the global energy perspectives from the IIASA/WEC includes three variants of future economy and energy development. Among the energy sources are renewable energy alternatives and biomass energy. The approach can be categorized as being expert judgment since the results are based on assumptions taken from literature and the technological and economic trends within the specific scenario. Renewable in general in all cases are driven by consumer demands fro more flexible, more convenient and cleaner energy.

Driving forces:

As mentioned above, IIASA/WEC developed three cases to study the near and longer term energy system; A (high growth); B (middle course) and C (ecologically driven).
The A case is further divided in three variants; A1, A2 and A3. Case C is further divided in two variants namely C1 and C2. Case A presents a future designed around ambitiously high rates of economic growth and technological ingenuity. Case B incorporates more modest estimates of economic growth, technological development, the demise of trade barriers, and the expansion of new arrangements facilitating international exchange. Case C is most challenging. It is optimistic about technology and geopolitics, but unlike Case A, assumes unprecedented aggressive international cooperation focused explicitly on environmental protection and international equity.
The market potential of renewable energy is base don scenarios taken from literature. The market potential growth of renewable energy is more gradual in the near to medium term ranging from 2.3 (case B) to 3.3 (A3 scenario) Gtoe by 2020. This more modest near-tem growth, is however, counterbalanced by high growth rates.

Population: In all three cases, a single medium projection of the world's population is assumed. It was chosen to use the same pattern of population growth in all cases so that the differences that emerge among the cases are more easily connected to differences in their energy system. It was chosen to use a scenario developed by the World Bank in which the global population doubles from 5.3 billion people in 1990 to 10.6 billion in 2060. Beyond 2050, population growth slows down significantly and global population stabilizes around 12 billion. In 2100 the value is 11.7 billion.

Economy: Within case A it was assumed that world GDP increases by an average of 2.7 % per year of 2050, and by 2.2 thereafter. By 2050, average world GDP per capita is US$ 10000, and would exceed US$ 25000 per capita by 2100. The single case B was expected t grow a little slower compared to case A; 2.1 % per year to a world GDP of US$ 75 trillion in 2050 and US$ 200 trillion in 2100.
The two cases C reflect aggressive efforts to advance international economic equity and environmental protection. It was assumed that the economic growth equals case B in 2050 (75 trillion) however exceeds case B in 2100 when a world GDP of 220 trillion is assumed.

Types of biomass included

Within the GEP study a distinction is made between commercial and non-commercial biomass energy. GEP calculates the land requirement for both food production and energy crops for Case A at the end of the study to discuss the feasibility of the results. The amount of biomass energy from dedicated plantation was taken from the LESS scenario.

Yield: In their feasibility study biomass land production was assumed to grow to 10 toe per ha per year.

Land requirements: To study the land requirements, the Basic Linked System (BLS) of agricultural models of IIASA was used. Based on the LESS scenario it was assumed that two-thirds of the biomass energy is produced on dedicated plantations and the remainder is recovered from agricultural residues as well as from forest residues. Both for agriculture (food) as well as energy plantations land is required, however it was stated that based on the simulations, the required land is available. Table B15.1 summarizes the current and future land use as assessed by the IIASA.

Table B15.1: Current and future land use according to IIASA

	Current use (Mha)			Additional land use (Mha)			Potential arable land (Mha)
	forest	pasture	agriculture	Agriculture (2050)	Biomass (2050)	Biomass (2100)	
Ics	1770	1190	670	50	70 – 100	150 – 350	n.a.
Africa	630	700	150	95	110 – 180	140 – 340	990
Asia	600	880	470	33	160 – 250	260 – 340	500
Latin America	890	590	150	72	50 – 80	140 – 320	950
DCs	2120	2170	770	200	320 – 510	540 – 1000	2440
World	3890	3360	1440	250	390 – 610	690 – 1350	-

Results:

The results (EJ) are taken from Internet and updated in 1998. The results are shown in Table B15.2 A1 – C2.

Table B15.2: Results from GEP

A1: Total biomass energy production

	1990	2000	2010	2020	2030	2050	2070	2100
North America	3.74	3.92	3.77	4.13	3.69	2.90	2.90	4.11
Western Europe	1.71	2.00	1.66	1.71	1.78	4.83	13.02	26.78
Pacific OECD	0.22	0.55	0.32	0.30	0.30	0.34	0.37	0.33
Former Soviet Union	1.35	1.73	1.68	1.97	2.91	7.07	2.91	5.25
Eastern Europe	0.30	0.27	0.25	0.25	0.52	0.78	0.28	4.46
Latin America	7.29	6.85	6.55	6.15	5.94	7.97	9.96	20.56
M. East&N. Africa	0.93	1.00	1.07	1.14	1.19	1.29	1.35	0.98
Africa	6.19	7.31	8.31	8.65	8.35	13.70	16.69	50.23
Centrally planned Asia	8.90	8.68	10.10	11.39	12.40	14.60	17.20	21.98
Other Pacific Asia	6.57	6.06	7.26	7.07	6.01	7.51	10.56	24.89
South Asia	9.01	10.20	11.31	12.50	13.57	16.72	20.03	25.65
World	46.21	48.59	52.29	55.26	56.66	77.71	95.28	185.23

B: Total biomass energy production

	1990	2000	2010	2020	2030	2050	2070	2100
North America	3.74	4.07	3.99	4.37	3.69	2.9	6.87	23.07
Western Europe	1.71	1.84	1.66	1.71	1.78	5.37	13.88	16.39
Pacific OECD	0.22	0.53	0.32	0.31	0.31	2.67	3.32	6.63
Former Soviet Union	1.35	1.41	1.57	1.6	1.73	3.3	7.2	30.01
Eastern Europe	0.3	0.27	0.25	0.28	0.23	1.24	2.54	2.7
Latin America	7.29	7.18	6.8	6.44	7.44	12.71	25.21	26.13
M. East&N. Africa	0.93	0.99	1.03	1.07	1.11	0.96	1.16	1.21
Africa	6.19	7.41	9.13	11.28	13.64	17.77	20.05	21.24
Centrally planned Asia	8.9	9.45	10.01	10.56	9.68	12.22	13.3	14.8
Other Pacific Asia	6.57	6.36	7.03	7.13	7	10.87	13.96	14.5
South Asia	9.01	9.88	10.62	11.38	12.14	13.62	15.05	16.97
World	46.21	49.38	52.42	56.14	58.73	83.65	122.54	173.65

A2: Total biomass energy production

EJ	1990	2000	2010	2020	2030	2050	2070	2100
North America	3.74	3.88	3.94	4.65	3.69	4.95	13.44	23.07
Western Europe	1.71	2.45	1.66	2.95	5.23	15.35	16.25	16.39
Pacific OECD	0.22	0.55	0.32	0.6	0.83	2.68	5.28	6.62
Former Soviet Union	1.35	1.74	1.82	2.21	2.44	5.55	14.46	30.01
Eastern Europe	0.3	0.28	0.45	0.92	1.28	4.1	7.04	7.51
Latin America	7.29	7.68	7.5	7.67	9.82	20.42	53.25	78.08
M. East&N. Africa	0.93	0.98	1.03	1.07	1.1	1.15	1.19	1.21
Africa	6.19	7.41	9.61	13.07	17.38	29.84	48.22	51.76
Centrally planned Asia	8.9	8.66	10.01	10.36	11.12	12.23	13.31	14.81
Other Pacific Asia	6.57	6.11	7.52	9.23	12.23	14.8	17.88	19.47
South Asia	9.01	9.88	10.62	11.38	12.13	13.62	15.05	16.97
World	46.21	49.61	54.5	64.09	77.24	124.68	205.33	265.91

A3: Total biomass energy production

	1990	2000	2010	2020	2030	2050	2070	2100
North America	3.74	4.63	7.99	11.66	17.05	16.63	32.59	37.37
Western Europe	1.71	2.61	3.86	5.72	8.46	15.84	26.23	26.78
Pacific OECD	0.22	0.56	0.73	0.98	1.35	2.68	2.36	0.45
Former Soviet Union	1.35	1.83	3.05	4.93	5.99	8.14	11.28	45.22
Eastern Europe	0.30	0.30	0.66	1.01	1.59	4.27	12.01	13.88
Latin America	7.29	7.47	8.34	8.99	11.62	26.18	34.42	54.36
M. East&N. Africa	0.93	0.89	1.08	1.13	1.19	1.28	1.36	1.41
Africa	6.19	7.63	10.29	13.34	16.60	29.83	51.89	66.37
Centrally planned Asia	8.90	8.74	10.53	11.40	12.40	14.61	17.21	21.98
Other Pacific Asia	6.57	6.77	8.93	10.86	12.14	17.84	21.70	24.29
South Asia	9.01	10.20	11.32	12.49	13.81	16.72	20.03	25.65
World	46.21	51.62	66.77	82.50	102.20	154.01	231.07	317.75

C1: Total biomass energy production

EJ	1990	2000	2010	2020	2030	2050	2070	2100
North America	3.74	3.77	3.77	4.13	3.69	2.92	6.95	11.2
Western Europe	1.71	1.61	1.66	1.71	2.23	6.93	13.3	18.28
Pacific OECD	0.22	0.36	0.24	0.3	0.3	1.69	3.15	2.16
Former Soviet Union	1.35	1.68	1.63	1.65	1.63	2.29	3.99	11.54
Eastern Europe	0.3	0.27	0.25	0.24	0.24	2.37	6.42	7.26
Latin America	7.29	7.65	8.25	9.08	10.77	16.62	28.98	34.58
M. East&N. Africa	0.93	1.01	1.08	1.14	1.2	1.05	1.35	1.41
Africa	6.19	7.1	8.13	9.46	11.95	21.39	39.91	87.35
Centrally planned Asia	8.9	8.87	10.53	11.4	11.98	14.61	17.21	21.98
Other Pacific Asia	6.57	6.27	7.25	8.09	7.83	10.6	16.4	24.89
South Asia	9.01	9.99	11.31	12.49	13.57	16.73	20.03	25.65
World	46.21	48.56	54.09	59.69	65.39	97.19	157.69	246.31

C2: Total biomass energy production

	1990	2000	2010	2020	2030	2050	2070	2100
North America	3.74	3.77	3.77	4.13	3.69	2.9	6.12	4.11
Western Europe	1.71	1.61	1.61	1.71	1.85	5.72	9.65	8.6
Pacific OECD	0.22	0.36	0.24	0.3	0.31	1.33	2.55	1.68
Former Soviet Union	1.35	1.68	1.62	1.6	1.62	1.99	2.91	5.26
Eastern Europe	0.3	0.27	0.25	0.24	0.24	2.16	4.58	5.83
Latin America	7.29	7.65	8.21	8.77	9.41	16.59	28.62	34.86
M. East&N. Africa	0.93	1.01	1.08	1.14	1.19	1.18	1.17	1.41
Africa	6.19	7.1	8.14	9.46	11.2	18.02	28.58	50.53
Centrally planned Asia	8.9	8.87	10.53	11.39	11.66	14.61	17.21	21.98
Other Pacific Asia	6.57	6.16	7.13	7.94	7.73	10.83	13.78	24.89
South Asia	9.01	10.01	11.32	12.5	13.51	16.72	20.03	25.66
World	46.21	48.48	53.89	59.19	62.4	92.05	135.2	184.82

B16. Name: BATTJES

(Battjes 1994)

Timeframe: 2050

Geographical aggregation: World; 13 regions

1.Canada
2. USA
3. Latin America
4. Africa
5. OECD Europe
6. Eastern Europe
7. CIS
8. Middle East
9. India + S Asia
10. China + C.P. Asia
11. East Asia
12. Oceania
13. Japan

Background: The study has been carried out with the IMAGE 2.0 version of the RIVM. Within this project two new biofuel scenarios have been constructed based on the existing Conventional Wisdom scenario prepared by the RIVM.

Driving Forces:

The two biofuel scenarios are constructed based on the Conventional Wisdom scenario prepared by the RIVM. The assumptions based on population and economic growth are based on World Bank estimates. According to the Conventional Wisdom scenario, less agricultural land will be used in 2050 in some regions (Canada, USA, Latin America, OECD Europe, Eastern Europe, CIS and Oceania). The land cover of these set asides are used for establishing energy plantations, instead of shifting it to its potential vegetation type. The biofuel scenarios are based on the most suitable crop according to the energy balance will be grown on these energy plantations.

Population: It was assumed that the population will about double by the year 2050 reaching 10 billion people.

Economic growth: The economic growth assumptions follow those of Scenario IS92a of the IPPC, and take into account recent changes in Eastern Europe and CIS, as well as consequences of the Persian Golf war.

Types of biomass included

The two biofuel scenarios only include the use of energy crops, with the most suitable crops according to the energy balance: Miscanthus. It was assumed that the energy crop will be used for electricity production.

Yield: The yield is modelled within the IMAGE model and assumed to depend on climatic factors as well as management factors. The latter was assessed by calibrating the potential productivity with the actual productivity.

Available area: The BF1 scenario assumes only set aside land, the BF2 scenario assumed set aside lands and 10% of the agricultural area in developing countries. Due to an increased management factor.

Results:

The results are converted from final energy by assuming an efficiency of 45% and shown in Table B16.1.

Table B16.1: The results in primary energy supply (EJ/yr) from BATTJES.

	BF1 scenario	BF2 scenario
Canada	2.4	2.4
United States	14.4	14.4
Latin America	11.3	15.1
Africa	0.0	17.6
OECD Europe	3.1	3.1
Eastern Europe	2.0	2.0
CIS	11.8	11.8
Middle East	0.0	0.0
India & S. Asia	0.0	11.8
China & CPA	1.1	13.3
East Asia	0.2	8.4
Oceania	0.7	0.7
Japan	0.0	0.0
Total	47.1	100.7

B17. Name: LESS-IMAGE

Timeframe: 1990-2100

Geographical aggregation: World, 13 regions:

Background: The so called Low CO_2-emitting Energy Supply Scenarios (LESS), developed for the working group II of IPCC, include one biomass-intensive variant (LESS-BI). LESS-IMAGE

Used Driving forces/scenario:

The LESS-IMAGE scenario is totally based on LESS-BI. The implementation of LESS-BI in IMAGE 2 aims to study the land use implication of the LESS-BI scenario which includes large amounts of biomass. This implementation therefore mimics precisely the specific energy requirements and energy carrier mix, including modern biomass in each region. Furthermore is referred to App. B11.

Types of biomass sources included

The LESS-IMAGE includes the same share of biomass types as LESS-BI, however, the focus is on energy crops, so only energy crop assumptions are included in this Appendix.

Yield levels: The yield levels were calculated within the IMAGE model.
For woody and non-woody perennial crops the productivity functions given by (Kassam, H.T. van Velthuizen et al. 1991) were used. Non-woody biofuel crops include a variety of grass species. Woody biomass includes several fuel wood species.

For modelling yields of sugarcane and maize the agro-ecological zones approach of FAO (FAO 1981) as described and implemented by (Leemans and Solomon 1993) and (Leemans and Van den Born 1994) was used.

These productivity models allow for the simulation of responses to climatic change and enhanced atmospheric CO_2 concentration (CO_2 fertilizing effect) and climate. A changing climate will change both the potential distribution of crops and their productivity. Yields under the LESS-IMAGE scenario are presented in Table B17.1

Table B17.1: global yield assumptions as calculated in LESS-IMAGE

GJ/ha/yr	1970	1990	2000	2025	2050	2075	2100
IMAGE-LESS	0	78	95	139	160	174	175

Required land: The area required for energy crop production is calculated in the land cover submodel of IMAGE. No restrictions regarding area needed for food production and forest areas were made. The demand for food and timber were done separately and tried to integrate when allocating land in the land cover submodel. The land cover model does not have a feedback to the energy model, so finally the demand for biofuels were satisfied.
Table B17.2 shows the global area requirement of LESS-IMAGE

Table B17.2 global area requirement of LESS-IMAGE

	2025	2050	2100
area required (Mha)	188	448	798

Results:

The results regarding biomass energy were of course similar as LESS-BI.

Appendix C

The assumed energy value of woody biomass is presented in Table C1.

Table C1: assumed energy value of woody biomass is presented

Acronym		HHV	LHV
WEC 94			15 GJ/tonne
GEP	Not specified		18 GJ/tonne[15]
SEI/greenpeace		20 GJ/tonne	
AGLU	Not specified		
SWISHER	Not specified		
U.S. EPA	Not specified		
SØRENSEN			
HALL		20 GJ/tonne	
RIGES		20 GJ/tonne	
LESS-BI		20 GJ/tonne	
LESS-BI / IMAGE		20 GJ/tonne	
BATTJES / IMAGE 2.0		20 GJ/tonne	
GLUE			15 GJ/tonne
GBP2050			18 GJ/tonne
DESSUS			18 GJ/tonne
SHELL	Not specified		
SRES		20 GJ/tonne	

[15] Was not expressed, but assumed since other studies with same models, which results were compared also used 18 GJ/tonne

Appendix D

Selection of studies of land availability for forest-based climate change mitigation strategies. Adapted from (Berndes 2000)

	Potential area for forestation strategies (Mha)	Approach
(Grainger 1988)	758	Areas of degraded tropical lands with potential for forest replenishment: 87 Mha Montane; 331 Mha drylands (297 Mha agriculture + 34 Mha irrigated cropland); 137 Mha humid tropics logged forests; 203 Mha humid tropics forest fallow.
(Grainger 1990) referred to in (Grainger 1991)	621	Three tropical zones: 331 Mha of desertified drylands, 203 Mha of forest fallows in the humid tropics, and 87 Mha of deforested watersheds in the montane tropics.
(Houghton, Unruh et al. 1991)	356-1079	Optimistic: 579 Mha of degraded lands in the tropics formerly covered with forests or woodlands, available to be planted, and managed as, plantations. 500 Mha of agricultural lands with potential for sequestering carbon through some form of agroforestry. Pessimistic: 0 Mha of degraded lands in the tropics formerly covered with forests or woodlands, available to be planted, and managed as, plantations. 356 Mha of agricultural lands with potential for sequestering carbon through some form of agroforestry.
(Houghton 1990)	865	500 Mha of degraded land with potential for plantations. In addition, conversion of land now in shifting cultivation to low input permanent cultivation, assumed to require only 15% of the land, would release 365 Mha of fallow forest from shifting cultivation.
(Bekkering 1992)	553	Maximum available area in 11 tropical countries with substantial potential for an expansion of the forest area.
(Nilsson and Schopfhauser 1995)	345	Both tropical and temperate forests. 275 Mha plantations and 70 Mha agroforestry
(Trexler and Haugen 1995)	545	Of the potential (natural and assisted forest regeneration=315 Mha; farm forestry=157 Mha; and plantations=73 Mha), 217; 61; and 67 Mha could be utilised by 2050. For regeneration and farm forestry, constraints other than land availability predominated.
(Myers 1989)	300	300 Mha would result in a net carbon sequestration that would end net accumulation of carbon dioxide in the atmosphere. A review of potential land for forest-planting lead the author to the conclusion that "...there should be no insurmountable difficulty, in principle at least, to finding 300 million ha of land for reforestation in the humid tropics". In a later paper (Myers & Goreau 1991) 200 million ha is considered "...a huge effort that is probably the most that can be envisaged at present".

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ANNEX 2

SUBPROJECT 1:

BIOMASS DEMAND FORECASTS FOR MATERIALS

Subproject 1

BIOMASS DEMAND FORECASTS FOR MATERIALS

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ECN Policy Studies

1. Introduction

Much attention is paid to biomass as an energy source in the discussion about the reduction of greenhouse gas emissions. However biomass can also be used as a source for materials. In this analysis the term biomaterials is used for such materials. Examples are: wood and wood board materials, paper and cardboard, detergents, natural rubber, and fibres such as cotton. Also synthetic organic materials, such as plastics, solvents and paints can also be manufactured from biomass. The use of charcoal for iron production constitutes another non-energy application because the wood carbon is used for chemical reduction of the iron ore.

The future demand for biomaterials depends on the future world population, the economic development and the price of fossil fuels. It is expected that CO_2 policy may increase the competitive edge of biomaterials, resulting in an increased demand. This can reduce the biomass availability of energy applications. From a GHG policy point of view, the optimal allocation of biomass for energy or materials and the trade-off with land use for afforestation depends on the CO_2 reduction that can be attained. This issue is not a part of this project, but of a separate project.

A second issue is the competition between primary biomass and secondary biomass for materials. For example waste paper can substitute virgin pulp, fibreboard can be manufactured from residue wood and waste wood, etc. The analysis of these chains requires a cascade approach. Cascading strategies have been considered in the following analysis.

This chapter consists of two parts: in section 2 an overview is given of the main results of the BRED project (Biomass for greenhouse gas REDuction). This study focused on Western European competition between bio-energy and biomaterials. Partly on the basis of the BRED results the demand for biomass as a source for materials is forecast in Chapter 3. The time horizon is 2000 - 2050. Possible secondary effects of climate change on materials requirements, income levels and population distribution are neglected.

2. Biomaterials at a European scale

2.1 The BRED project

The objective of the “Biomass for greenhouse gas REDuction” project is to analyse the optimal application of biomass in Western Europe in the coming decades, in order to reduce greenhouse gas emissions (Gielen et al 2000). The project is a part of the Environment and Climate programme of the European Union. The MARKAL (MARKet ALlocation) MATTER 4.2 computer model has been used for model calculations, a model specially developed to analyse strategies for emission reduction. The model allows modelling of physical material flows 'from cradle to grave'. These life cycles are described via several hundreds of processes. With the help of the model the optimal system energy and materials systems configuration is calculated. Optimal refers in this case to maximised social welfare with endogenised environmental impacts. For example CO_2 penalties can be added in order to simulate the effects of an environmental tax. Processes with relatively high costs but low emissions can become more attractive because competing technologies are taxed. As a part of the BRED project three scenarios have been analysed and for each scenario different CO_2 emission levies have been applied: 20, 50, 100, 200 Euro per ton CO_2. The run without levy is the base case (BC).

The BRED results for biomaterials that are discussed refer to the 'Globalisation' scenario, characterised by fast technological progress, globalisation of economical activities and liberalisation of the energy market. The results for 2030 are discussed, unless indicated otherwise. A much more detailed discussion of the MARKAL model, the biomass module, the scenarios used and the results can be found in the final BRED report (Gielen et al, 2000). The input data for the model are presented in five separate reports (eg Feber and Gielen 2000, Koukios and Diamantidis 2000). The input data and all publications can also be found on the Internet (www.ecn.nl/unit_bs/bred/main.html).

2.2 Biomaterials versus bio-energy

Figure 1 shows the use of biomaterials and bio-energy in the base case. Materials use dominates until 2000. In 2010 the quantities of bio-energy and biomaterials are equal those for energy. From 2010 onwards bio-energy dominates, although still about 40% of all non-food crops are used for the production of biomaterials.

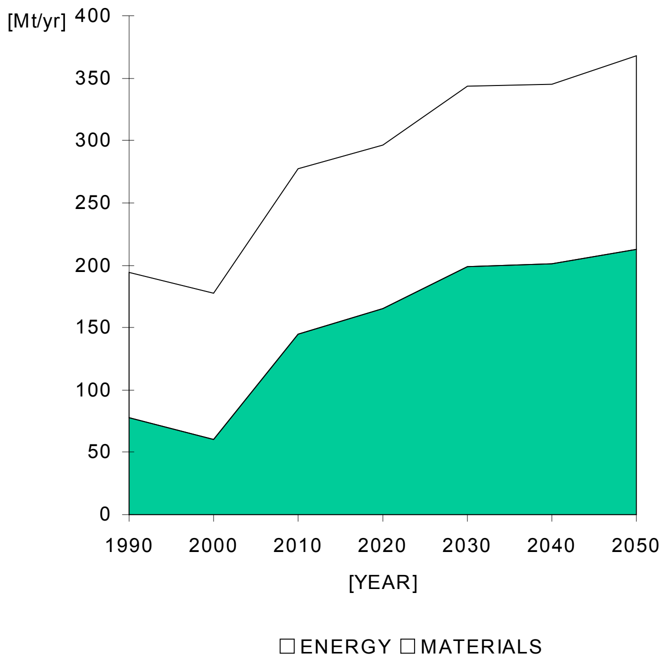

Figure 1. Biomass use, base case, 'Globalisation' scenario, 1990-2050

The use of biomass (both in terms of quantity and type of application) changes when greenhouse gas policies are implemented. Figure 2 shows the total biomass supply for food, energy and materials for different CO_2 tax levels. The reference year 1990 is shown in the leftmost column, then the base case (without tax) and three tax levels in 2030.

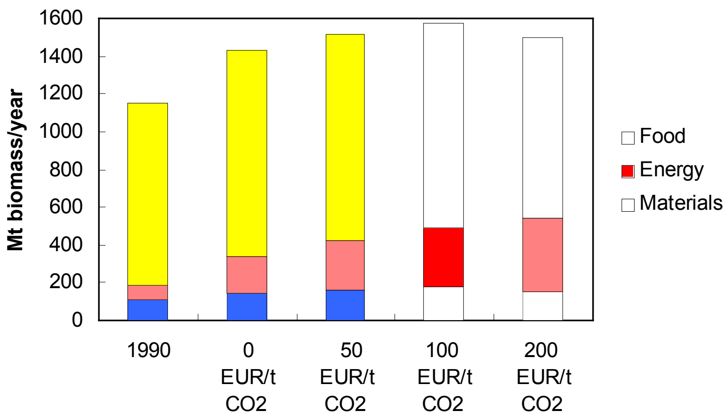

Figure 2. Biomass use, increasing taxes, 'Globalisation' scenario, 2030

According to figure 2 the market for materials increases until a level of 100 EUR/ton CO_2, but decreases again at 200 EUR/ton. The maximum use of biomaterials (at 100 EUR/t CO_2) amounts to 175 Mt primary biomass. Roughly one-third of all non-food crops is used for biomaterials. The total *extra* contribution (as a result of greenhouse gas policy) for energy and material applications is 200 Mt at most (at 200 EUR/ton CO_2). Food applications dominate bio-energy and biomaterials at all tax levels. The following paragraphs discuss the various markets for materials in more detail.

2.3 Biomaterials

The market for biomaterials can be divided into bio-chemicals, building materials and pulp (paper). The aggregated results for biomaterials are shown in figure 3. The growth of the market for biomaterials up to a tax level of 100 EUR/t CO_2 is largely the result of an increased biomass use for the production bio-chemicals, as well as a modest increase in the market for building materials. The decrease at higher tax levels results from the switch of HTU oil use from the petrochemical sector to the transport sector.

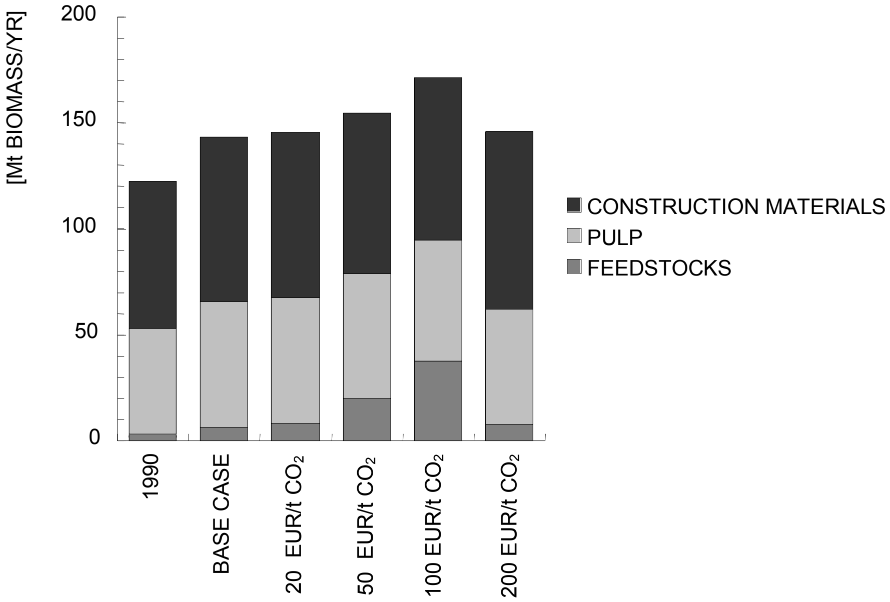

Figure 3. Application of biomaterials at increasing CO_2 taxation levels, 'Globalisation' scenario, 2030

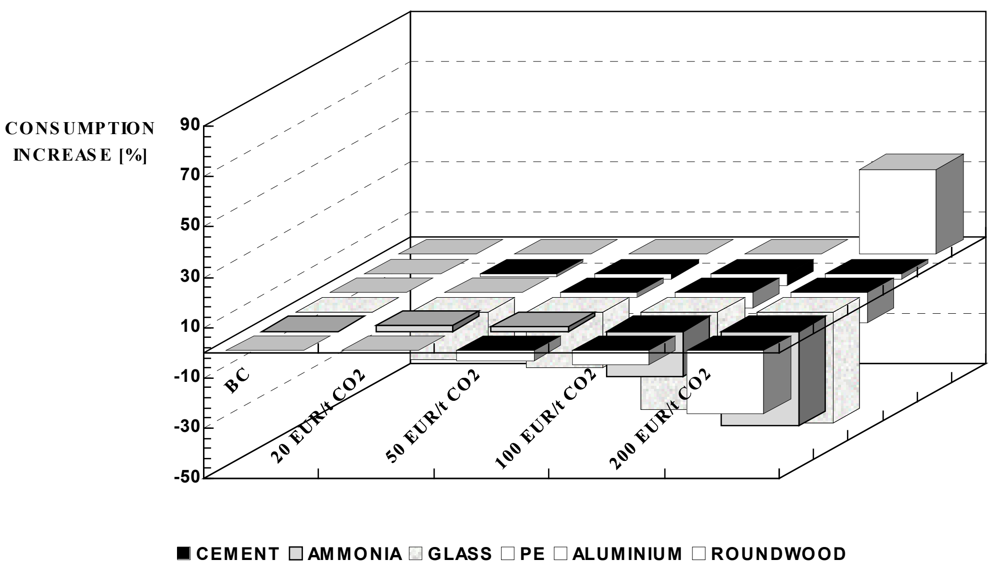

Figure 4. The effect of greenhouse gas policy on the consumption some important materials

Figure 4 demonstrates how the implementation of a greenhouse policy affects the consumption of materials in general. If emission levies are applied, the use of cement and glass decreases considerably, and polyethylene and aluminium decreases somewhat. The demand for round-wood increase at higher levies. These changes result from the interaction between material substitution, increased efficiency and a lower demand because prices increase.

2.3.1 Bio-chemicals

Petrochemical products can be divided into plastics, solvents, detergents, resins and a number of less important applications. Plastics and synthetic fibres are the most important products. Within this market segment polyethylene, polypropylene, polyvinylchloride and polystyrene occupy three-quarters of the market. Substitution of oil based materials with biomaterials is possible at the intermediate or final product level. Intermediates such as ethylene, propylene, butadiene and aromatic compounds such as benzene, xylene and phenol can be manufactured from biomass by means of a combination of pyrolysis and gasification technologies.

Biomass consists of different substances: oils, sugars, starch, cellulose, hemi-cellulose and lignin. Every component offers different possibilities. Alcohols such as methanol, ethanol, i-propanol and butanol, acetic acid and acetone can be manufactured by fermentation of biomass or by gasification and subsequent synthesis. Natural oils and resins can be used to produce detergents, lubricants and paints.

Natural rubber, which currently represents one third of the total rubber production, occupies the high quality segment of the rubber market. Cotton and natural polymeric cellulose fibres, such as rayon, compete with synthetic organic fibres such as nylon and polyester. The packaging market seems to be most appropriate for the substitution of traditional polymeres by bio-polymeres. Cellophane and new bio-polymeres such as biopol (a co-polymere of polyhydroxybutyrate PHB en polyhydroxyvalerate PHV), plastics based upon starch and poly lactic acid are considered in the model as alternative options. Figure 5 shows the changing petrochemical product mix for increasing tax levels.

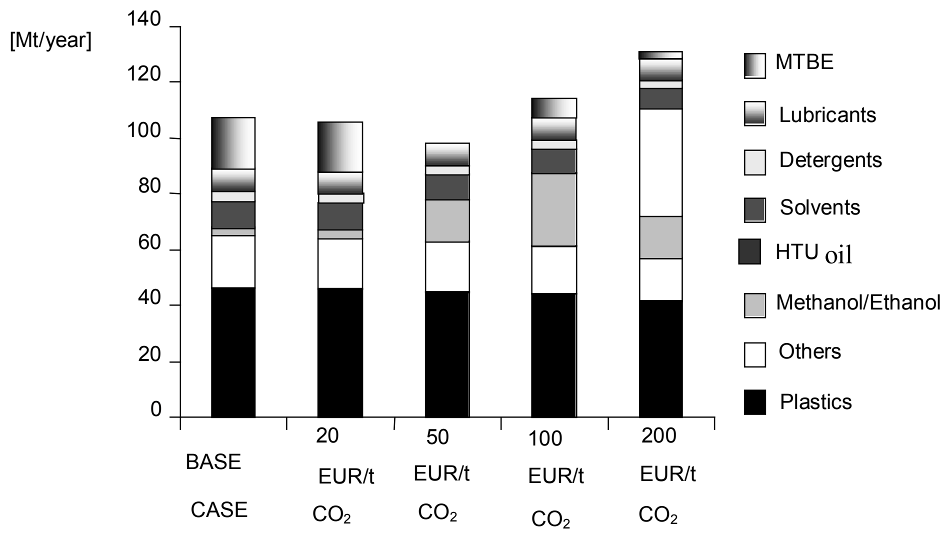

Figure 5. Production of petrochemicals, increasing CO_2 taxation levels, 'Globalisation' scenario, 2030

Figure 6 illustrates the way biomass is used in the petrochemical industry. The following technologies are important: ethanol production from wood, ethylene and butadiene production through flash pyrolysis, production of methanol from straw and the production of bio-diesel from HTU oil. It should be noted that flash pyrolysis and HTU oil cracking have not yet been proven on a commercial scale.

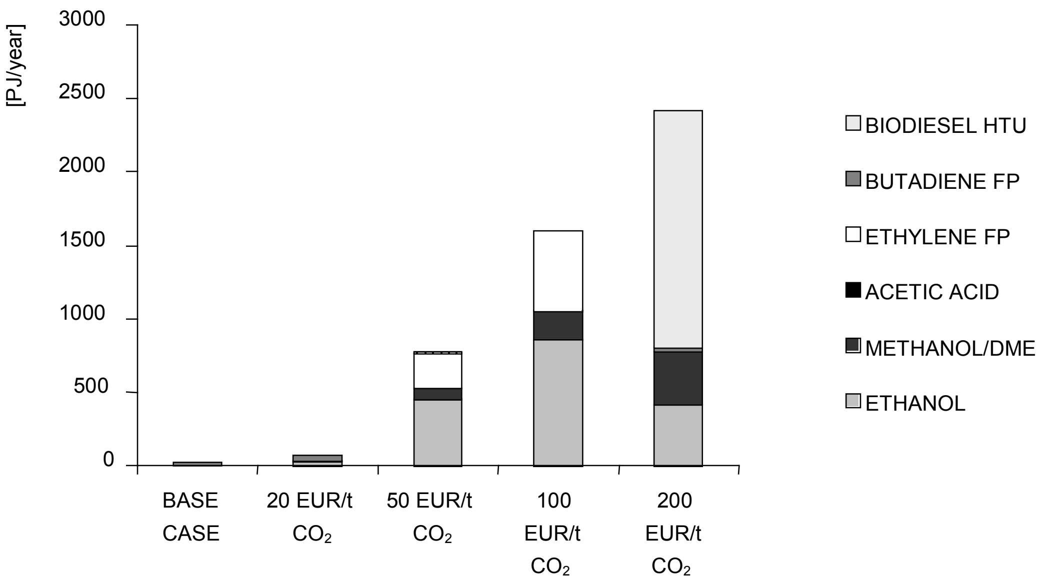

Figure 6. Biomass use in petrochemistry, increasing CO_2 taxation levels, 'Globalisation' scenario, 2030

Also some production processes for final products such as bio-plastics become cost-effective at higher emission levies. However the amounts of biomass required for the production are small compared to the amounts needed for the production of bulk commodities (such as ethylene). As a result these production routes are only of secondary importance from the point of view of greenhouse gas emission reduction, and therefore they cannot be found in figure 6. Because of the cumulative market volume of these routes, they still deserve attention.

On the basis of the results of the BRED study one can conclude that the production of *intermediate* products on the basis of biomass is economically more attractive that the production of *end* products. The direct production van bio-chemicals (such as viscose, cellophane) is not attractive. However biomass can become attractive for the production of existing intermediates in the petrochemical chain (e.g. ethylene, butadiene). Presently most of the interest within the industry is focused on direct production. This suggest that or the present model input data do not reflect the optimistic estimates of the industry, or that the industry has not yet paid sufficient attention to the potential of bio-feedstocks as a substitute for oil and gas feed stocks for existing petrochemical products. Possible bottlenecks are the availability of technology, costs, the availability of biomass and the absence of a suitable infrastructure for the use of biomass in present petrochemical industry.

2.3.2 Building materials
Sawn wood is the most well known biomaterial for construction purposes. Some other materials, such as particleboard, fibreboard and MDF are of secondary importance from the point of view of mass flows. Wood products can substitute concrete, steel or bricks in the building or construction sector.

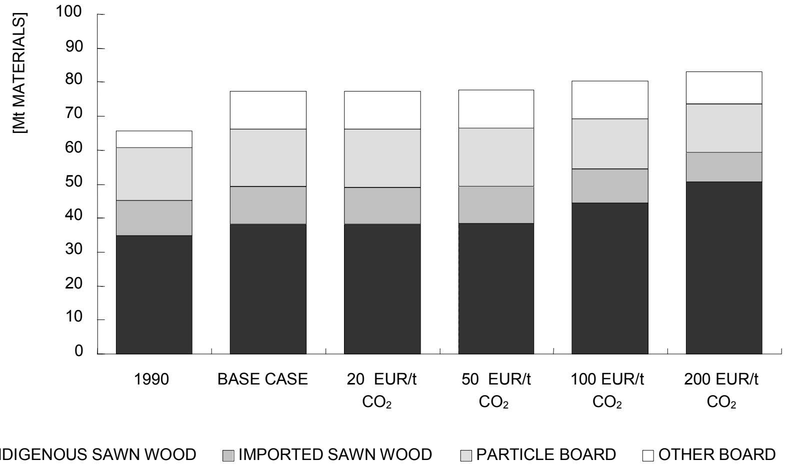

Figure 7. Wood construction materials, increasing CO_2 tax levels, 'Globalisation' scenario, 2030

Figure 7 illustrates the results for the use of wood in the building and construction sector. The base case shows a small increase compared to the reference year (from 65 to 80 Mt). The amount increases to 85 Mt in case a greenhouse gas tax is applied. This small increase is the result of the combination of a strongly increased demand for sawn wood and a decreased demand for particleboard and MDF. Sawn wood is used in the building sector, to replace concrete of other building material. Board materials are applied particularly in the furniture market, which presently is being dominated by wood. The decreasing demand resulting from higher prices dominates the increase by substitution in the sector, reason why the total increase of biomass remains limited.

2.3.3 Pulp and paper
Figure 8 shows the total paper production in 2030, in the 'Globalisation' scenario. In the model a significant growth of the European paper consumption has been assumed, based upon the present trends and the existing correlation between paper consumption and GDP-growth. The GDP is growing with a factor 2.5 - 3 whereas the paper consumption increases with a factor of 1.5: a de-coupling based upon the assumption that an increasing use of technologies such as the Internet will partly replace the use of paper.

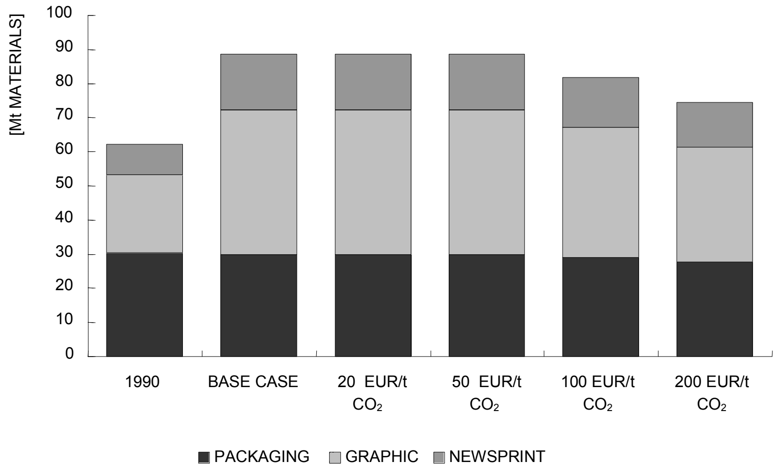

Figure 8. Paper consumption, increasing taxes, 'Globalisation' scenario, 2030

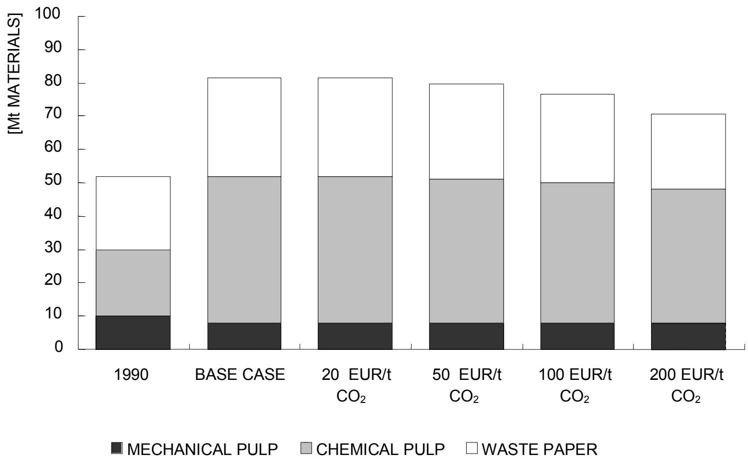

Figure 9. Pulp use for paper production, increasing taxes, 'Globalisation' scenario, 2030

In figure 9 the pulp mix for the paper production is shown. Because of the ample biomass supply potential in Europe, according to the BRED calculations, used paper will be used for energy purposes and nor for recycling (see also section 2.4). This explains why figure 9 shows an increasing demand for fresh fibres and a decreasing demand for used paper when the taxes increase. With respect to the reference year recycling increases to 30 Mt per year in 2030 (an increase of 50%). The use of chemical pulp in that period increases to 44 Mt per year (more than a doubling). The effect of the taxes is limited.

The recycle ratio decreases from around 40% in 1990 to 37% in the base case in 2030. The recycle ratio is defined as the quantity of recycled fibres divided by the total amount of fibres used. The driving force behind this decrease (and the increase in the use of chemical pulp) is a co-production strategy: lignin is a co-product of the chemical pulp production, which can be used for energy production (with a high efficiency via new gasification technology plus CHP). Also energy can be generated from used paper.

2.4 Cascades and co-production

By using biomass first as material and then as energy source, more emissions of greenhouse gases can be avoided than by using biomass directly for energy purposes. Particularly when the availability is limited it is important to use biomass as efficient as possible.

To demonstrate the importance of cascades the energy recovery from waste biomaterials is shown in figure 10. Energy recovery from waste biomaterials increases by a factor eight even without additional policy measures. This increase results from the combined effect of waste policy, increasing costs to dump waste and the increased efficiencies of waste treatment technologies. Co-firing of waste wood in power plants is not taken into account because of air pollution problems.

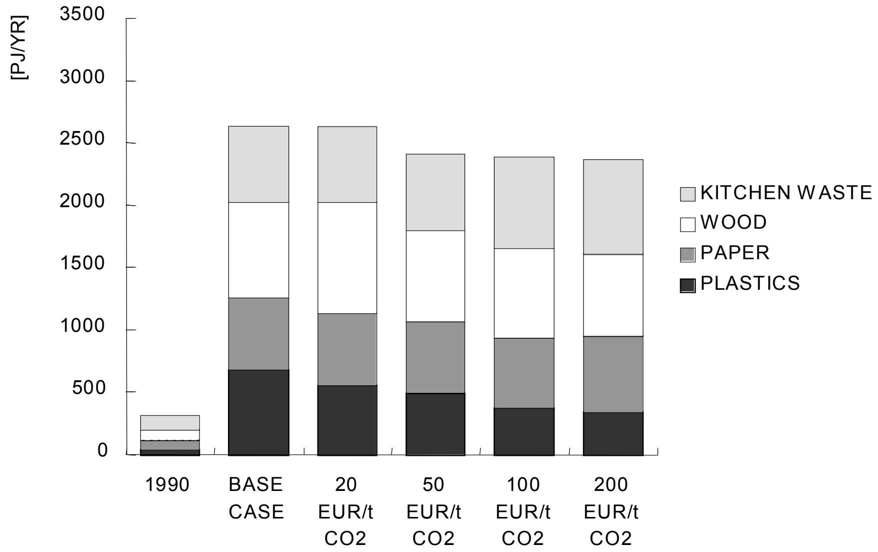

Figure 10. Energy generated from waste, increasing levies, 'Globalisation' scenario, 2030

The BRED results suggest that cascading strategies are of secondary importance. The reason is again the large European biomass potential. However as a result of greenhouse gas policy co-production of bio-energy and biomaterials emerges emerge in the production of bio-chemicals and ethanol. Lignin is a co-product of the production of ethanol from wood. Energy is generated from lignin through gasification and subsequent CHP. Lignin can probably also be used for the production of HTU oil. Lignin is also a co-product of chemical pulp production. The total amount of paper pulp does not increase, however, because of greenhouse policies. But, less recycling takes place and the use of chemical pulp increases. The amount of sawn wood is not being influenced significantly by greenhouse policies. The relevance of co-production is limited until about 1 EJ of bio-energy (high levies). Generally co-production deserves more attention.

2.5 Recommendations for future studies

Considering biomaterials and European biomass use in general, the following issues should be analysed in more detail:

- The impact of more wide system boundaries including Eastern European countries. Eastern European agricultural productivity can be improved considerably. In case Eastern European countries join the EU, the final results may change because more cheap land will be available for biomaterials production and for energy farming.
- Analysis of the potential of straw, and particularly the competition between the use for energy and material applications and the improvement of soil quality. Straw can be used for producing heat and biofuels. There is still quite some uncertainty about the potential amounts of straw available.
- The potential of new bio-chemicals, such as acetic acid, iso-propanol, surfactants and PUR. The model results indicate that most of the growth prospects exist in the market for these and similar materials.
- A detailed analysis of the interaction between the building materials choice and the energy use during the life of the building. The analysis has shown that the results are fairly sensitive for the energy costs and CO_2 emissions during the life of the building. Small differences in the heating energy may lead to more widespread use of wood skeleton buildings. This analysis deserves more attention because this has a large influence on the demand for biomaterials.
- Analysis of the effect of ‘carbon leakage’ and the effect of changing worldwide trade flows in agricultural and forestry products. By introducing emission levies in Europe the costs of production will increase to such levels that production outside Europe will become cheaper. As a result, European production may decrease in favour of foreign producers. The problem of ‘carbon leakage’ is relevant from the perspective of greenhouse policy.

3. Biomaterials on the world scale

3.1 Factors influencing future demand for biomaterials

The future demand for biomaterials depends upon the future world population, the economic development and the price of fossil energy carriers. Based on the European analysis an estimate will be made of the future global demand for biomass as a source of materials. Note that this analysis constitutes only a rough first estimate. More analysis is warranted.

The future world population has been estimated on the basis of data of the World Resources Institute (WRI), which in turn are based upon the data of the UN Population Division. The present size of the world population is 6 billion people. The UN expects the world population to increase to about 8 billion in 2025, i.e. an annual increase of 1.15%.

The future GDP growth has been estimated by taking the average of the four SRES scenarios of the Intergovernmental Panel on Climate Change (IPCC). The global GDP growth between 1990 and 2020 is estimated at 3% per annum.

In addition it is assumed that the future demand for biomaterials will be stimulated by greenhouse policies. This is particularly relevant for synthetic organic materials, wood and pig iron. The estimates below constitute a maximum demand scenario for biomaterials. Also an indication shall be given of the land area required to produce the biomass. This is relevant because applications of biomaterials compete with other biomass strategies such as direct use of the biomass for energy purposes and afforestation for carbon storage.

3.2 Estimates of future material flows per market segment

The market for biomaterials can be divided into the following segments: pulp for paper production, petro-chemicals, wood and board materials, charcoal to replace cokes and coal in the production of pig iron, cotton and natural rubber.

Pulp

The present global production of pulp (excluding used paper, but including alternate fibres, such as straw, hemp and cotton) is 175 Mt, according to the Food and Agricultural Organisation (FAO). The amount of used paper in the world is around 110 Mt, or about 40% of the total pulp production. Generally it is assumed that there is a good correlation between the demand for paper (and pulp) and the GDP growth, because the use of paper strongly depends upon economic development and the growth of the world population. Assuming an income elasticity of 1, global pulp production will increase by 3% per year until 2020. According to the statistics of the Confederation of European Paper Industries (CEPI) the growth of the pulp production in CEPI countries (with 17 Western European member countries) between 1983 and 1997 was 2.6%. Therefore a global growth figure of 3% seems justified.

If one assumes that recycling increases simultaneously to 50% then the biomass demand for the production of pulp increases to about 275 MT in 2020. This value is shown in the third column of table 1 in paragraph 3.3. The fourth column presents the amount of primary biomass to produce 1 ton of biomaterial. For pulp a value of 2 has been assumed, based upon the efficiency of producing chemical pulp (50%).

For biomass this leads to a somewhat optimistic estimate, because roughly half of the production of paper is based upon chemical pulp. The other types of pulp processes show higher efficiencies.

Petrochemistry
The petrochemistry data are based upon Gielen and Yagita (2000). Data for the so-called FREAK model (FoReign trade Effect Assessment Kit, a global model for the petrochemical industry) have been collected on the demand for petrochemicals, subdivided in product type and region. Also trends are given until the year 2025. With these data the present global demand for petrochemicals is estimated at 200 Mt/year, and at 550 Mt/year for 2020.

It is assumed that the production of 1 ton of bio-chemicals requires about 2.5 tons of primary biomass. This is estimated on the basis of the heating value of petrochemicals (about twice that of biomass), plus an addition because of lower conversion efficiency of the biomass).

Wood
Sawn wood and board materials are in this category. Much information on wood is available from the FAO statistics and the UN-ECE Trade Division. The present production of sawn wood, according to FAO statistics, is more than 400 million m^3 (about 250 Mt), and the production of board materials is 150 million m^3 (about 100 Mt). On the basis of the prognosis of GDP growth and FAO projections the assumed growth for wood and board materials is 2.6% and 5% respectively (European Timber Trends, 1996). It is also assumed that the application of wood in the building sector will be stimulated through national policies, and this results in extra use of wood.
The conversion efficiency of primary biomass into sawn wood and board is assumed to be around 50%, with reference to Scharai-Rad (1999) and the UN-ECE Timber database.

Pig iron
According to the statistics of the International Iron and Steel Institute (IISI) the present global pig iron production amounts 550 Mt. Pig iron is basis for steel production through the Blast Oxygen Furnace (BOF) process. The total global steel production is currently 775 Mt. Approximately one third is produced with the Electric Arc Furnace (EAF) process (based on scrap). The global steel production is fairly cyclical in nature. Average growth amounted during the last few years to about 1% per year. If we assume that that this trend continues, the global steel production will reach about 1000 Mt in 2020. If about 30% of this amount is produced with the EAF process, this implies that the pig iron production (BOF) is around 700 Mt in 2020.
It is assumed that 0.7 ton of primary biomass is required (for the production of charcoal) per ton of pig iron. Charcoal replaces coal in the production of pig iron. It is assumed that cokes will not be replaced by charcoal (although this is technically possible) and that the ratio charcoal/cokes is 50/50. See also Gielen and Van Dril (1997).

Cotton
The FAO statistics show that the present world production of cotton is 20 Mt. We assume that the combination of economic development and population growth leads to an annual growth of 4%, until a total of 40 Mt in 2020.

Rubber
The present world production of natural rubber is 7 Mt (FAO statistics). With an annual growth of 3%, based upon historical trends, the rubber production in 2020 reaches about 13 Mt.

3.3 Future demand for biomaterials

Table 1 shows all estimates of the preceding paragraph. The total amount of biomass required for the production of all these biomaterials is around 4500 Mt. With the estimated yield per hectare in column 7 (depending on the type of soil and crop) the total required land area is 775 Mha (see column 8). With a total available agricultural area of 5000 Mha, about 15% of that area are required for the production of materials.

Table 1. Future global demand for biomaterials with active stimulation

Material	Demand 2000 [Mt/yr]	Demand 2020 [Mt/yr]	Market share biomass [%]	Bio-mass use [t/t]	Bio-mass use [Mt/yr]	Yield [t/ha]	Land required [Mha]	Type of Land
Pulp	175	275	100	2	550	5	110	Forest/ plantation
Petro-chemistry	200	550	100	2.5	1375	10	140	Forest/field/grass
Wood	350	1000	100	2	2000	5	400	Forest/ plantation
Pig iron	550	700	100	0.7	490	5	100	Forest/ plantation
Cotton	20	40	100	1	40	2	20	Field
Rubber	7	13	100	1	13	2	6.5	Forest/ plantation
Total					*4468*		*775*	

After processing part of the materials in table 1 becomes a resource that can be used to generate energy. In the production of pulp the so-called 'black liquor' is a residue (50% of the primary biomass becomes black liquor). In the production of sawn wood roughly 50% is turned into residues (such as sawdust). This means that from the total amount of 4468 Mt of biomass 1275 Mt becomes residue,

This calculation assumes that 100% of the required biomass consists of primary biomass. In principle part of the sawing residues and part of the wood and board available after its use, can be applied again for material purposes. An upper value of cascading benefits can be calculated by neglecting any losses.

Wood process residue and re-use:	2000 Mt
For petrochemicals:	1375 Mt -/-
For pulp:	550 Mt -/-
Remains:	75 Mt (for charcoal)

With these assumptions (maximum cascading) the total amount of biomass required is reduced to 2000 + (490-75) +40 + 13 = 2468 Mt. The area required to grow this amount is 509 Mha. With regard to the biomaterials cascade it should be noted that residue wood in the building sector is only available after 40 to 200 years.

Table 2 shows the demand for biomaterials in the case that no positive incentives are provided to use biomaterials. These data can be compared to the developments in the area of bio-energy in the absence of incentives. They may also serve as a reference in case one would make a policy choice for bio-energy without optimising the use of biomass.

Table 2. Future global demand for bio-material without proper incentives

Material	Demand 2000 [Mt/yr]	Demand 2020 [Mt/yr]	Market share biomass [%]	Biomass use [t/t]	Biomass use [Mt/yr]	Yield [t/ha]	Land required [Mha]	Type of land
Pulp	175	275	100	2	550	5	110	Forest/ plantation
Petro-chemistry	200	550	10	2.5	140	10	14	Forest/field/grass
Wood	350	600	100	2	1200	5	240	Forest/ plantation
Pig iron	550	700	5	0.7	25	5	5	Forest/ plantation
Cotton	20	30	100	1	30	2	15	Field
Rubber	7	10	100	1	10	2	5	Forest/ plantation
Total					*1955*		*389*	

The demand for biomass without incentives becomes 1955 Mt, with a required area of 389 Mha. This is about half of the area required in the situation when biomass is actively stimulated (Table 1).

The data from table 1 and table 2 can be translated to energy. With an average energy content of 16 GJ/t the use of biomass for materials translates into 31-71 EJ per year. Note that a comparison of bio-energy and biomaterials on the basis of their energy content is misleading because the yield per hectare differs per crop type.

4. Conclusions and recommendations

The conclusions of this study on the use biomass for materials are as follows:

- An integral analysis of the optimal use of biomass and the optimal land use is important in order to arrive at a proper conclusion regarding bio-energy potentials (this should be the subject of the complementary OPTIBIO study, also carried out in the framework of the GAVE programme).
- The demand for biomaterials is strongly influenced by policies. A doubling is possible.
- The worldwide area needed for biomaterials in 2020 ranges from a maximum of 775 Mha (with greenhouse policy) to 389 Mha without such policy.
- The largest markets for biomaterials are: production of sawn wood, board materials, pulp, bio-chemicals and charcoal for the production of pig iron. Perhaps the combination of petro-chemistry and refineries offers opportunities to combine the production of materials and transport fuels.
- Afforestation strategies (to store carbon) may reduce the availability of biomass on the medium to long term (10 to 50 years). (see also the results of the BRED study, Gielen et al., 1999, 2000)
- With regard to the CO_2 effect of material savings the BRED results show, both for materials and energy, that the CO_2 effect of substitution depends upon the ambition level of greenhouse gas policies. The CO_2 intensity of the reference situation also changes considerably, because other renewable sources are introduced. It is also important to include in such an analysis the methane emissions from landfill sites and the emissions of N_2O in the case nitrogen fertilisers are used. The way in which carbon storage in products should be accounted is unclear as of yet. It constitutes a key issue for the optimal use of biomaterials. One should also take indirect effects into account, such as the effect of material choices in the case of space heating and/or cooling. A proper estimate of the combined greenhouse effect of the proposed measures is a complex problem, beyond the scope of this study.
- Costs and cost effectiveness are not analysed in this study. Generally one can state that the prices of materials per unit of weight are considerably higher than the prices of energy carriers. The BRED results show a 2:1 distribution of materials and energy respectively in case of optimal biomass use.
- Also the BRED results show that the main problem for biomass in Europe is not its availability, but the relatively high costs compared to alternative measures.
- Translating these results to the situation in the Netherlands is a difficult process, full of uncertainties. The Netherlands is a small player in the world biomass market, without adequate national supply basis. Timely long-term agreements with foreign producers should be considered in order to reduce this uncertainty.

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ANNEX 3

SUBPROJECT 2:

EXPLORATORY STUDY ON THE LAND AREA REQUIRED FOR GLOBAL FOOD SUPPLY AND THE POTENTIAL AREA AND PRODUCTION OF BIOMASS FUEL

Exploratory study on the land area required for global food supply and the potential area and production of biomass fuel.

Report for GRAIN project,

'Global Restrictions on biomass Availability for Import to the Netherlands'

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1. Introduction

The purpose of this study is to calculate the available land areas on this globe that in the future may be available for the production of biomass for energy production. This wil be derived from a comparison of the maximum global food production and the potential global food demand. The higher the global production in comparison to the food consumption, the larger becomes the fraction of the agricultural land that can be used for other crops than food crops. This can be fibre crops or crops that can be used as biomass fuel.

This major part of the report is based on the study 'Sustainable world food production and environment' (Luyten, 1995). In this study the future food demand in the different regions of the world was calculated. This food demand was calculated from their population in the future and the food demand per person in dependence of the assumed diet. It was determined if this food demand could be met by food production assuming different agricultural practices. The potential food production in 15 large regions of the globe was calculated. Note that this potential food production is technically feasible in the long term but that this production is very high compared the actual food production and that it requires considerable changes in the agricultural production systems at the global scale. The comparison of potential food production with food demand in the different regions indicated the self-sufficiency (i.e. supply / demand) in food supply per region. From this the fraction of agricultural land that may be available for biomass (or other) production in the future, could be derived. In this report mainly the global results (i.e. summary of results from the 15 regions) is presented and used.

In Chapter 2 three population growth scenarios and three consumption patterns are described, and the resulting global food demands are given. In Chapter 3, two different agricultural production systems are described. The procedures for calculating the land area suitable for agricultural production and the crop yields, and the resulting world food production are given. In Chapter 4 the world food demand is compared with the global food supply. This shows the degree of self-sufficiency in food supply for different agricultural practices, diets and population size and indicates the fraction of the agricultural land area that can be used in the future for biomass production. From this the maximum area available for biomass production and the potential production of biomass fuel are determined (Chapter 5). In Chapter 6 the underlying assumptions of the study by Luyten are discussed and the resulting uncertainties in world food supply and demand and thus in the potential area for biomass production. Other factors that might cause a different potential for biomass production, are described. In Chapter 7 the main conclusions are given.

Note that the study mentioned above will be indicated in this report by Luyten (1995) but that it was carried out by a large number of people. J.P.M. Dijkman, M. de Savornin Lohman, R. van Buren and M. Vis (Delft Hydraulics, Delft, the Netherlands) performed the water availability calculations. The development of the crop growth modelling system, the calculations of the crop yields over the globe and the reporting of this study was done mainly by J.C. Luyten and P.S. Bindraban (AB-DLO, Wageningen, the Netherlands). For an article on this study, see Penning de Vries et al. (1995).

2. World population and food demand

Food demand in the future is determined by the population size in the future and the food requirement per person which depends on the consumption pattern.

2.1 Population growth scenarios

The United Nations (1992) published population projections from year 2000 until 2150 in steps of 25 year. These projections were made for both a low, a medium and a high population growth scenario For year 2040, the future year used in this study, the population size was estimated by linear interpolation between the 2025 and 2050 projections. The global population size in years 1990 and 1998 and the estimates for year 2040 are given in Table 1.

Table 1. Global population size in years 1990 and 1998 and the estimates for year 2040 for a low, a medium and a high growth scenario (Source: FAO statistical data base; Luyten, 1995).

Population (10^9 people)

Year 1990	**1998**		**2040**	
		Low growth	Medium growth	High growth
5.29	5.90	7.73	9.40	11.29

2.2 Consumption patterns

The world food requirements were calculated for three different food consumption patterns: a vegetarian diet, a moderate diet and an affluent diet. The composition of these diets in amounts of plant, dairy and meat products is given in Table 2. The vegetarian and the moderate diets represent respectively a very moderately and a moderate consumption pattern, but they are satisfactory diets with respect to daily caloric intake and daily protein requirement. The minimum daily caloric intake for an adult is 10 MJ (Bakker, 1985) and the minimum daily protein requirement is on average 1.0 g per kg body weight (Passmore and Eastwood, 1986). The affluent diet can be considered as the upper limit for food consumption, as mostly found in rich societies, and includes a much higher meat consumption.

To make the diets comparable (Table 2), the diets are expressed in grain equivalents. Grain equivalents refer to the amount of dry weight in grains needed as raw material for the consumed products plus some additional costs to grow food that cannot be produced in the form of grains (such as fruit). The diets are composed of plant, dairy and meat products, each product with its specific conversion factor for grain equivalents. These conversion factors are the weighted averages of the conversion factors for the different consumed products.

The amount of grain equivalents required for the affluent diet is almost twice that for the moderate diet and more than three times that for the vegetarian diet (Table 2). The average daily consumption per adult is set at 1.3, 2.4 and 4.2 kg (dry weight) in grain equivalents for the vegetarian, the moderate and the affluent diet, respectively.

The mean daily consumption per caput at present in the world was derived from the FAO food balances. This mean diet was compared with the three types of diet and appeared to be slightly more affluent than the moderate diet (Table 2), when expressed in grain equivalents.

Table 2. Average daily consumption per adult, with its energy intake and protein intake for a vegetarian, a moderate and an affluent diet, the conversion factors from food (fresh weight) to grain (dry weight), and the resulting grain equivalents. The conversion factors differ between the diets because of their different composition (Source: Luyten, 1995). For comparison the mean daily consumption per caput in the world in year 1997 as calculated in the FAO food balances, was given (Source: FAO statistical data base).

	Consump-tion (g/day)	Energy intake (MJ/day)	Protein intake (g/day)	Conversion factor (g grain equiv./g product)	Grain equivalents (g dry weight/day)
Vegetarian diet					
Plant products	1335	9.36	66.7	0.8	1053
Dairy products	122	0.69	8.6	2.6	286
Total	1457	10.05	75.3	0.92	1339
Moderate diet					
Plant products	1134	7.73	50.0	0.8	908
Meat products	23	0.30	3.8	9.4	215
Dairy products	469	2.03	27.4	2.4	1232
Total	1626	10.05	81.2	1.45	2355
Affluent diet					
Plant products	938	6.69	28.9	1.2	1138
Meat products	225	2.84	36.7	8.5	1907
Dairy products	354	2.01	26.5	3.3	1161
Total	1517	11.54	92.1	2.77	4206
Actual mean diet					
Plant products	1166	9.81	46.9	0.8[a]	933
Meat products	108	0.99	13.1	9.4[a]	1015
Dairy products	282	0.86	14.0	2.4[a]	677
Total	1556	11.66	74.0	1.69	2625

[a] This actual mean diet was about similar to the moderate diet and identical conversion factors were used.

2.3 Global food demand

Total annual food demand is the product of the global population size (Table 1) and the food consumption per adult (Table 2). The amount of grain equivalents required to feed the world population at present (years 1990 and 1998) and in year 2040 is given in Table 3. These results were calculated for the population size at present and in the future for the three population growth scenarios and for the three diets.

Table 3. Global food demand for three diets and the actual population size in years 1990 and 1998 and the estimated population size from three growth scenarios for year 2040, as expressed in grain equivalents (10^{12} kg dry weight per year) (Source: Luyten, 1995).

Vegetarian diet			Moderate diet			Affluent diet		
Year	**1990**	**1998**	**Year**	**1990**	**1998**	**Year**	**1990**	**1998**
	2.51	2.80		4.64	5.17		8.11	9.05
Year	**2040**		**Year**	**2040**		**Year**	**2040**	
Low growth	Medium growth	High growth	Low growth	Medium growth	High growth	Low growth	Medium growth	High growth
3.67	4.46	5.36	6.77	8.24	9.89	11.85	14.42	17.31

3 Agricultural production

3.1 Data base

To calculate the crop production for the range of environmental conditions on this globe, both a global weather data base and a global soil data base were used in the study by Luyten (1995).

3.1.1 Weather data

The weather data base used in this study was derived from the global data base compiled by Müller (1987). This is a global set of long-term monthly average values of weather variables from a large number of meteorological stations. For most stations these average weather data were based on observations during the period from 1931 to 1960. The weather data base contains data on the following variables: 1. minimum daily temperature; 2. maximum daily temperature; 3. daily irradiation; 4. monthly precipitation; 5. monthly number of rainy days.

For the calculations of crop production, the minimum and the maximum temperature were used to determine the duration of the potential growing season. Both temperature and irradiation were used to calculate the crop production. To determine the soil water supply and the degree of growth limitation by water shortage, the mean monthly precipitation and the number of days with precipitation were used. The mean monthly values of the weather variables in the data base were assigned to the day numbers at the middle of the months. By linear interpolation between these mean monthly values the daily values of temperature and irradiation were derived. Daily rainfall was generated by a random generation of the average monthly rainfall over the average monthly number of rainy days (Supit et al., 1994).

The calculations of crop production were done for a data base with a grid of 1^0 longitude and 1^0 latitude resolution (i.e. amply 100 km * 100 km near equator) across the globe. With a standard algorithm, each grid cell was allocated to the nearest meteorological station, thus creating a map of climatic zones. Within a zone the weather data were derived from that nearest station.

3.1.2 Soil data

A digitised soil data base from NASA (Zobler, 1986) was used for the study by Luyten (1995). This data base was based on the Soil Map of the World, scale 1:5,000,000 (FAO/UNESCO, 1974-1981). The digitised data base contains a large number of records, each record representing a grid cell of $1^0 * 1^0$. The record contains information on the soil type, characteristics, texture class and slope gradient of the dominant soil unit per grid cell. Grid cells are only included in the data base if 50% of their area is covered by land. This soil information was used to derive the parameters required for the modelling of crop production. For example, the water holding capacity of the soil that determines the degree of soil water supply under drought conditions, was derived from the soil texture class. This was done in a way similar to that applied in a study for the European Union (Reinds et al., 1991).

3.2 Production systems

Two different production systems were defined for calculating the global food production. In the High External Input (HEI) system crop production was assumed to be maximized, to use all external inputs (mechanized operations, chemical fertiliser, biocides, etc.) required to attain that high yield level, and to be realized under optimum management. This resulted in an efficient use of nutrients for production, in an effective control of weeds, pests and diseases (i.e. yield losses assumed to be nil) and hence, in a high efficiency in the use of the applied inputs. This system applied the so-called 'best technical means' and the information on this system was mainly based on the common agronomic practices in current Dutch agriculture (De Koning et al., 1992). In this system crop production was only limited by the availability of water, if no irrigation water could be applied.

In the Low External Input (LEI) system crop production was realized under optimum management too but both best technical and ecological means were assumed to be applied. This means that environmental risks were minimized and that no chemical fertilizers and biocides were applied. Nitrogen was entered in this system mainly by biological fixation in the root nodules of leguminous crops. This required a crop rotation of one leguminous crop and two grain crop on arable lands and a grass-clover mixture on permanent grasslands. The availability of other nutrients (in particular phosphorus and potassium) was assumed to be optimal, which required a sufficient supply through recycled waste products and application of natural fertilisers (e.g. compost, animal manure, and rock phosphate). In this system crop production was limited by both nitrogen and water availability. The information on this system was based on currently applied techniques and cultivation practices in integrated, ecological and biological production systems in the Netherlands (Vereijken, 1990; Vereijken and Wijnands, 1990). The control of weeds, pests and diseases differed from that in the HEI system. Herbicide application was replaced by mechanical weeding. The control of pests and diseases was replaced by prevention of infestations by way of judicious crop rotations and biological control. Yield losses by mainly pests were assumed to increase in this system to 10%.

3.3 Duration of potential growing season

The total production per year depends on the crop yield level and the number of crops that can be grown within a year. The duration of the growth period of most crop is mainly determined by a specific temperature sum and becomes shorter due to faster development with rising temperature. Other factors such as solar radiation, water or nutrient supply have practically no influence on this duration.

A procedure that scanned the daily course of minimum and maximum temperatures throughout the year, was applied to identify periods with temperatures suitable for crop growth. The temperature constraints for the growing seasons were: 1. temperatures during the growing season required to be between 0 and 40°C;
2. Temperature sums (above base temperature of 0°C in temperate regions and of 10°C in tropical regions) of 1600 and 1850°C.d to complete growth period of an early, short growing and a late, long growing crop variety, respectively (Van Heemst, 1986, 1988). If the accumulated temperature sum exceeded these minimum crop requirements, a next growth period during that year was determined. Between both growth periods, an intercrop period of 2 weeks for the HEI and of 4 weeks for the LEI system has been assumed. The maximum number of growth periods per year was set at 3 for the LEI and at 4 for the HEI system, but the scanning procedure applied to the whole globe resulted in a maximum of 3 growth periods for the HEI system.

3.4 Suitable area for agriculture

To calculate the global food production, the potentially suitable areas for farming were assessed. The suitability of land for modern farming was defined in the study by Luyten (1995) as the fraction of the area that is suitable for mechanized cultivation and on which crops can be grown without soil-related constraints. The remaining area could not be used for cropping and was available for other purposes, such as nature, infrastructure and recreational areas. The basis for this suitability assessment was the NASA data base (Zobler, 1986). Grid cells in the data base were classified into 26 soil types, 19 soil characteristics and 9 slope gradients. For each of these three factors a value between 0 and 1 was assigned, based on criteria applied by FAO (1978) and expert knowledge. The product of these fractional suitabilities gave the overall suitability for modern farming. The suitable area has been corrected for the area occupied by lakes and rivers, but not for areas used for cities, forests and other non-agricultural purposes. The total land area and its overall suitability for modern farming and for grassland are given in Table 4.

Table 4. Total global land area (in 10^9 ha) and the average fraction of the land that is suitable for modern arable farming and for grassland, as determined by Luyten (1995).

Total area	Suitability grassland	Suitability arable farming
12.20	0.637	0.312

LEI systems may be less demanding in terms of soil suitability than HEI systems, but such a distinction was not made in the study by Luyten (1995) for lack of specific information.

Land suitability was assessed separately for arable farming and grassland, because arable cropping requires better soil qualities than grassland. In the model procedure grain crops were produced first on all land suitable for arable production. The remaining land, if suitable, was used for grassland. For comparison, data on the currently used land for arable farming and for grassland according to the FAO were compared with the calculated land areas (Table 5). They agree reasonably well, although actual arable land areas may considerably expand. FAO agricultural land area data for year 1998 are used as 'actual agricultural land area' and computed land area data are used as 'potential agricultural land area' in the following analysis.

Table 5. Total land area, agricultural land area, land area for arable production and for permanent grassland in the world, all in 10^9 ha, computed by the model and according to FAO data for years 1990 and 1998. FAO data were given for areas currently under respectively arable and permanent cropping and permanent grassland. The modelled data were given for areas potentially suitable for respectively arable cropping and permanent grassland minus arable production area (Sources: Luyten, 1995; FAO statistical data base).

	Total land	Agricultural land	Arable land	Grassland
FAO 1990	13.04	4.91	1.50	3.41
FAO 1998	13.05	4.94	1.51	3.43
Model	12.20	7.78	3.80	3.98

3.5 Food production

Total crop production per year is the product of crop yield and the number of crops per year. Actual crop yields were often below the maximum attainable level because of water and/or nitrogen shortage during crop growth. These aspects were considered in the model calculations, as treated in the following.

3.5.1 Crop growth model

A simple crop growth simulation model, LINTUL, was used in the study by Luyten (1995) to calculate yields under the range of environmental conditions on this globe LINTUL calculates crop growth with time steps of a day as product of the amount of intercepted radiation and the efficiency of radiation use for biomass production (set to 3.0 g dry biomass per MJ intercepted (photosynthetically active) radiation). The radiation interception is limited during juvenile growth (i.e. small leaf area which increases over time), is maximum during the main growth period, and decreases near final crop senescence. The basic ideas of LINTUL were described by Spitters (1987, 1990). LINTUL requires few input data and data to calibrate model parameters and can easily be applied for a global study with limited information.

LINTUL simulated two 'standard' crops with characteristics comparable to those of current major cereals and grass. Grain and grass differed only in the value of the harvest index (HI, i.e. fraction harvested of the total above-ground dry biomass). The following values for HI that were representative for the current major cereals (Van Duivenbooden, 1996) were used: 0.4 (LEI, grain), 0.45 (HEI, grain), 0.7 (LEI, grass), and 0.6 (HEI, grass).

The HI value for a grain crop under the LEI system is lower than that under HEI system because of nitrogen stress under LEI that accelerates self-destruction (Sinclair & De Wit, 1976). HI for LEI is higher than that for HEI , which assumes that LEI grasslands are exploited better and have a higher quality. All yields were expressed in grain equivalents in the Luyten study.

Yields were lower than the potential yield level, if the water supply (in situation without irrigation) or the nitrogen availability (only in LEI system) became limiting for crop production. To simulate crop growth under water-limited conditions, a soil water balance routine was included in the model. This routine calculated the changes in the amount of available soil water over time from the incoming water by precipitation and possibly irrigation and from the water losses by crop transpiration, soil evaporation, and percolation to the subsoil. If the soil water content decreased below a critical level, both the transpiration and the biomass production decreased to the same extent. This routine can also be used to calculate the irrigation water requirements.

To simulate growth under nitrogen-limited conditions (i.e. LEI), assuming that the other nutrients were sufficiently available, a soil nitrogen balance routine was included in the model. In the LEI system a rotation of one leguminous crop and two grain crops was assumed for arable cropping and a grass-clover mixture for the permanent grassland. This resulted in the model in a nitrogen supply from mainly biological N fixation of 90 kg N ha^{-1} yr^{-1}. This N supply was only 35 to 50% of that for a crop in the HEI system and hence, yields were proportionally lower. The multiplication of this N supply with the recovery fraction of supplied N for crop uptake (about 0.40) and the biomass yield-nitrogen uptake ratio of the crops (set equal to 120 and 112 kg dry matter per kg N for the LEI and the HEI systems, respectively, as based on N concentrations in grains and straw) gave the N limited biomass yields for both grain and grass crops. More details on the soil nitrogen balance and the soil water balance routines in LINTUL were given by Luyten (1995).

3.5.2 Calculation method

The calculation of the crop production in the world was done in the following order:

1. The length of the growing season and the number of growth periods per year were determined for each climate zone, as determined by its temperature conditions.
2. The potential and the water-limited crop yields were calculated for all combinations of soil characteristics, climate conditions and growth period in each grid cell and the irrigation water requirements for potential production were also determined.
3. For the LEI system the nitrogen-limited yield was calculated. If this yield level was lower than the potential and water limited yields (assuming ample N supply) as calculated in step 2, these two yield levels and the corresponding irrigation water requirements were reduced to the level of the N-limited yield.
4. Production volumes per grid cell were calculated for both HEI and LEI systems with and without irrigation. This was done by aggregation over the total land area of the grid cell of the yields calculated for the different soil-climate-growth period combinations.
5. Soil suitabilities were calculated for each grid cell (section 3.4). These soil suitabilities (i.e. fraction of the land suitable for modern farming) were multiplied with the production volumes and the corresponding irrigation water demands per grid cell.

6. Available irrigation water was allocated to grid cells (section 3.5.4). It was assumed that irrigation water was applied to arable crops but not to grassland.
7. Results from all grid cells have been aggregated and average values for food production were computed for the 15 major regions of the world and the world as a whole.

3.5.3 Crop yields

Irrigated grain production (i.e. potential production) per cropping season ranged from 2000 to 12000 kg (dry matter) ha^{-1} in the HEI system and from 1500 to 3000 kg ha^{-1} in the LEI system. In combination with up to three growing seasons per year, annual production ranged from 4000 to over 25000 kg ha^{-1} for the HEI system and from 2000 to nearly 7000 kg ha^{-1} for the LEI system. The water-limited yields varied much more strongly over the world than the irrigated yields. In very dry areas (i.e. desert areas such as parts of Africa and Australia) water-limited yields were nil, whereas in areas with high precipitation (e.g. Central Africa, Indonesia) the yields were close to the potential yield level.

Irrigated and water-limited yields in the LEI system were considerably lower than those in the HEI system. This was due to the fact that the nitrogen supply was the limiting factor in the LEI system. In most areas (except for desert areas) the water-limited yields in the LEI system were not determined by the water availability but by the more limiting nitrogen availability.

For more information on typical yield ranges of grain crops and permanent grassland in the study by Luyten (1995), as calculated for HEI and LEI production systems in both temperate and tropical climate zones with and without irrigation, see Penning de Vries et al. (1995).

3.5.4 Food production

Maximum global food production is the production volume that can be realized if all available land is cropped and all available water resources are used for irrigation of arable crops. The water availability for irrigated agriculture in each river basin on the globe was calculated in the study by Luyten (1995). Available irrigation water was allocated to the grid cells to determine the irrigated arable cropping area. Table 6 gives the maximum global food production, both on the potential and the actual agricultural land area, specified for irrigated and rainfed production and Table 7 gives the corresponding arable areas.

In the HEI system on the potential agricultural land area maximum global food production amounted to $72 * 10^{12}$ kg grain equivalents. Irrigated global food production was four times larger than the rainfed production (Table 6). Grasslands could provide $29 * 10^{12}$ kg grain equivalents.

The arable cropping area was 49% of the total potential agricultural area (Table 5), and contributed 60% to total food production. 65% of the arable cropping area was irrigated (Table 7), but this irrigated area contributed 82% to total arable crop production. Hence, 49% of the total global food production originated from irrigated arable land.

Table 6. Global total food production in years 1990 and 1997 as calculated[1] on the basis of the FAO food balances and maximum global food production (in grain equivalents, 10^{12} kg dry matter yr^{-1}) in the future as calculated for the HEI and the LEI systems both on the actual (Act; Table 5: year 1998) and the potential (Pot) agricultural land area. This production comprises production from irrigated crops, rainfed crops and permanent grassland (Source: Luyten, 1995).

Year 1990				**Year 1997**			
Total production				Total production			
	3.91				4.44		
HEI_{Pot}				**LEI_{Pot}**			
Total prod.	Irrigated crops	Rainfed crops	Rainfed Grass	Total prod.	Irrigated crops	Rainfed Crops	Rainfed grass
72.26	35.18	7.90	29.18	30.67	14.19	0.67	15.81
HEI_{Act}[2]				**LEI_{Act}[2]**			
Total Prod.	Irrigated crops	Rainfed crops	Rainfed Grass	Total prod.	Irrigated crops	Rainfed Crops	Rainfed grass
45.88	22.34	5.02	18.53	19.47	9.01	0.43	10.04

[1] Calculated as total cereal production minus cereal use for animal feeding times dry matter content in grains (=0.88) times a ratio for the mean diet. This ratio is equal to (energy intake per caput in plant products * 0.8 + energy intake in dairy products * 2.4 + energy intake in meat products * 9.4) / (energy intake per caput of cereals * 0.8). See Table 2 for the conversion of products to grain equivalents.

[2] To calculate the food production for the HEI and the LEI systems on the actual agricultural land area it was assumed that identical fractions of land were used for irrigated crops, rainfed crops and rainfed grass and that the yield levels were the same as those calculated for the potential agricultural land area.

In the LEI system the nitrogen supply was the main yield limiting factor in most areas and not the water supply. Consequently, the yields and thus the water requirements were low, and a much larger area (92% of arable area) could be irrigated than in the HEI system (Table 7). This irrigated area was very large compared to the actual irrigated area. Maximum global food production on the potential agricultural land area amounted to 31 * 10^{12} kg grain equivalents, which was about 40% of the food production in the HEI system (Table 6). The arable cropping area was 49% of the total agricultural area (Table 5), but it contributed only 48% to total food production (Table 6). 46% of the total global food production originated from irrigated arable land.

In the study by Luyten (1995) all the land that is potentially suitable for food production was assumed to be used. This resulted in an increase in agricultural land by roughly 50% compared to the actual agricultural land area (Table 5), and thus in a similar and very large loss of nature and forest areas. Feber & Gielen (2000) calculated the potential global demand in year 2020 for biomass as a source for producing materials such as pulp, biochemicals, sawn wood, wood for pig iron production, cotton and rubber. This possible material demand would require the use of a land area of 0.78 * 10^9 ha, which is about 35% of the difference between the potential and the actual agricultural land area.

As it is imaginable that a drastical increase in agricultural land area is not acceptable or possible for these two reasons, the food production calculations were also done for the actual agricultural land area, which are roughly two third of the potential agricultural area. For these calculations it was assumed that the yield levels were the same as those calculated for the potential agricultural area and that fractions of land used for irrigated and rainfed crops and rainfed grass remained identical. The global food production in both HEI and LEI systems on the actual agricultural area was reduced by roughly one third compared to that on the potential area (Table 6).

Table 7. Global arable areas (in 10^9 ha) with and without irrigation observed (i.e. arable and permanent cropping areas) in years 1990 and 1998, computed with the model (i.e. potential arable land areas: Pot) for the HEI and the LEI systems in the future (Sources: Luyten, 1995; FAO statistical data bases) and calculated for both systems on the actual agricultural land area (Act).

Year 1990			**Year 1998**		
Total	Irrigated	Rainfed	Total	Irrigated	Rainfed
1.50	0.24	1.26	1.51	0.27	1.24

HEI & LEI$_{Pot}$	**HEI$_{Pot}$**		**LEI$_{Pot}$**	
Total arable	Irrigated	Rainfed	Irrigated	Rainfed
3.80	2.46	1.35	3.50	0.31
HEI & LEI$_{Act}$	**HEI$_{Act}$**		**LEI$_{Act}$**	
Total arable	Irrigated	Rainfed	Irrigated	Rainfed
2.41	1.56	0.86	2.22	0.20

The actual total food production as calculated from the FAO food balances, was low (Table 6) compared to the global food demand calculated for the moderate diet (Table 3). This lower total food production (about 85% of the global demand) may be explained from overestimation of the food demand, which was calculated for a population of only adults. The total actual production was very low compared to the production of the HEI system but also compared to that of the LEI system. This last system is more attainable for most regions of the world and thus is better for a comparison with the actual production situation.

The LEI production on the actual agricultural land area is still much higher than the actual production because first its arable and most productive area is much larger (+60%) than the actual arable area, second the irrigated area is 8 times the actual irrigated area (Table 7) with irrigated yields being roughly two times the rainfed yield level, and third the actual yields on permanent grasslands which generally are on more marginal soils and are less intensively used, probably are much lower than the grass yields in the LEI system. These factors caused an actual production that was only 23% of the LEI production level (Table 6).

3.5.5 Crop residues

Total production of residues from arable crops is equal to the total arable production times (1-HI)/HI. This is 0.55/0.45 * total arable production (i.e. 43 * 10^{12} kg dry matter yr^{-1}) for the HEI system and 0.6/0.4 * total arable production (i.e. 15*10^{12} kg dry matter yr^{-1}) for the LEI system (Table 6), assuming that only grain crops are cultivated. Crop residues are used for animal feeding, for maintaining the organic matter content of the soil, and for other purposes, such as local fuel supply. As a rough and very optimistic estimate, one third of the total production of residues may be available as biomass fuel.

A number of reasons can be mentioned why the fraction of crop residues available as fuel supply is probably smaller. First, if the organic matter content of the soil decreases because of smaller supply of crop residues, a number of problems may arise related to soil fertility and soil structure. Soils with low organic matter content may show silting up of the topsoil, which results in surface runoff and thus in loss of rainfall water and increased risk for soil erosion and drought (e.g. in Sahelian region). Soils in the tropics often have a low moisture holding capacity and a small exchange capacity for nutrients, which only can be improved by increasing the soil organic matter content. If not, this results in yield reduction by drought even in relatively humid climates and in large leaching losses of nutrients (e.g. after fertilizer and manure application) from the rooted soil layer. To use these soils for ‘high input’ farming, the soil organic matter content should be maintained. Second, part of the nutrients that are used by the crop for its growth, are taken up from the soil after decomposition of residues of the previous crop. In systems with low inputs of nutrients from external sources (e.g. fertilizer and manure) a larger part of the nutrient supply is depending on this residue decomposition than in a HEI system. Hence, the fraction of residues to be used as biomass fuel is relatively high in a HEI system and very low in a LEI system. Third, crop residues are already used as a local fuel supply in the rural areas of less developed and poor societies. In addition to that use, the use of crop residues in urban areas may remain limited due to the decentralized production of residues and the large volume of residues per unit energy. This may cause problems with transportation and may require decentralized conversion plants.

4. Food production versus food demand

The potential global food productions in the future as calculated for the HEI and the LEI systems, were compared with the global food demand in year 2040. This global food demand was determined for three population growth scenarios and three diets (section 2.3). The ratio between the food production and the food demand indicates the food security situation. A ratio equal to 2 is assumed to be the minimum, because food production between years may vary, because unequal income distribution may keep food inaccessible to the poor if food supply is limited, and because in addition to food crops also other crop (e.g. fibre crops, vegetables, fruit crops) are grown. The ratios between food supply and demand at the global scale are given in Table 8. As food cannot be transported to an unlimited extent between regions with food excess to regions with food shortage, these ratios may show a too favourable picture for the food security situation in the world.

Table 8. Ratio between global food production in the future as calculated for the HEI and LEI systems on the potential (Pot) and the actual (Act) agricultural land areas, and global food demand as determined for three population growth scenarios (i.e. low, medium, and high population growth) and three diets (i.e. vegetarian, moderate, and affluent diet) (Source: Luyten, 1995).

	Vegetarian diet			Moderate diet			Affluent diet		
Prod. System	Low growth	Medium growth	High growth	Low growth	Medium Growth	High growth	Low growth	Medium growth	High growth
HEI_{Pot}	19.7	16.2	13.5	10.7	8.8	7.3	6.1	5.0	4.2
LEI_{Pot}	8.4	6.9	5.7	4.5	3.7	3.1	2.6	2.1	1.8
HEI_{Act}	12.5	10.3	8.6	6.8	5.6	4.6	3.9	3.2	2.7
LEI_{Act}	5.3	4.4	3.6	2.9	2.3	2.0	1.7	1.3	1.1

The ratio of the global food production and the global food demand ranged between 1.8 and 20 in dependence of production system, diet and population growth (Table 8), when the food production was calculated for the potential agricultural land area. The ratio decreased when the food production was calculated for the actual agricultural area, and ranged then between 12 and 1.1 . If these ratios were calculated separately for large regions, their variation became much larger as discussed further on (section 6.3). When the HEI system of farming is applied on the potential agricultural area, the production/demand ratios indicate that an affluent diet is available for the total global population in year 2040 and that large areas of potential agricultural land can be used for the production of biomass fuel. The production/demand ratios for the LEI system indicate that an affluent diet is still available for the total global population but that no agricultural land is left for the production of biomass fuel. If only the actual agricultural land is used in the future, an affluent diet is still available for the future global population if the HEI system is applied, but the land area available for biomass production becomes much more limited. The LEI system on the actual agricultural land area will supply only a moderate diet to the future global population, but no land area is available for biomass production (Table 8).

In the highly developed and wealthy societies the HEI system of agriculture, an affluent diet and a low to medium population growth is to expected. In the less developed and poor societies agriculture should be based more on local resources and the LEI system may then be applied in the future. This may be combined with a medium to high population growth and a mainly vegetarian diet. It is interesting to observe that the production/demand ratios for these most probable systems are roughly identical (i.e. about 5 and 3.5 if respectively potential and actual agricultural land areas were used).

5. Maximum areas available for biomass production and the potential production of biomass fuel

The ratio between the global food production and the global food demand (Table 8) was used to calculate the fraction of the agricultural area that may be used for the production of biomass fuel. As described above in section 4, the production/demand ratio should be at least 2 for food self-sufficiency. For example if the ratio is equal to 5, 40% of the agricultural area is needed for food production and the other 60% may be used for other purposes. The maximum fraction of agricultural land and the maximum agricultural land areas that may be available for the production of biomass fuel, are given in Table 9. It is assumed that all agricultural areas inclusive the areas that cannot be used for arable cropping but only for permanent grassland (Table 5), can be used for the production of biomass fuel. If only the actual agricultural land areas can be used, the land areas available for biomass production become much smaller than the areas available in case the potential areas are used, and in particular if the LEI system is applied (Table 9).

Table 9. The maximum fraction of agricultural land and the maximum agricultural land areas (in 10^9 ha) on this globe that may be potentially available for the production of biomass fuel, assuming HEI or LEI systems for food production on the potential (Pot) and actual (Act; Table 5: year 1998) agricultural land areas and different global food demands as based on three population growth scenarios (i.e. low, medium, and high population growth) and three diets (i.e. vegetarian, moderate, and affluent diet).

	Vegetarian diet			Moderate diet			Affluent diet		
	Low growth	Medium Growth	High growth	Low growth	Medium Growth	High growth	Low growth	Medium growth	High growth
Fract. area									
HEI_{Pot}	0.90	0.88	0.85	0.81	0.77	0.73	0.67	0.60	0.52
LEI_{Pot}	0.76	0.71	0.65	0.56	0.46	0.35	0.23	0.05	0.00
HEI_{Act}	0.84	0.81	0.77	0.71	0.64	0.57	0.49	0.38	0.26
LEI_{Act}	0.62	0.55	0.44	0.31	0.13	0.00	0.00	0.00	0.00
Total Area									
HEI_{Pot}	7.00	6.85	6.61	6.30	5.99	5.68	5.21	4.67	4.05
LEI_{Pot}	5.91	5.52	5.06	4.36	3.58	2.72	1.79	0.39	0
HEI_{Act}	4.15	4.00	3.80	3.51	3.16	2.82	2.42	1.88	1.28
LEI_{Act}	3.06	2.72	2.17	1.53	0.64	0.00	0.00	0.00	0.00

The potential production of biomass fuel can be calculated as the product of the available areas (Table 9) and the biomass yield per hectare. It can be assumed that the production of biomass fuel is done without irrigation and with both a HEI and a LEI production system, and that the harvest index of the biomass crop (section 3.5.1) and thus the yield level is roughly the same as that for grassland. The mean global yield of rainfed grassland in both systems was calculated from the maximum global rainfed grass production (Table 6) and the total global rainfed grass area (Table 5), and was equal to 7300 and 4000 kg dry matter ha^{-1} yr^{-1} for respectively the HEI and the LEI system.

The potential production of biomass fuel was calculated for these yield levels and the potentially available areas in dependence of the assumed food production system, diet and population growth scenario (Table 10). The potential global biomass production is strongly dependent on the agricultural area that is required for food production, and may vary from nil to 28 * 10^{12} kg biomass dry matter yr^{-1} for respectively the LEI agricultural system with a very high food demand and the HEI system with a very low food demand, if the potential agricultural land area is used and the LEI system is applied for biomass production. In a highly developed and wealthy society the HEI system in combination with a high food demand results in 20 * 10^{12} kg biomass dry matter yr^{-1} and in a less developed and poor society the LEI system in combination with a low food demand results in about the same result for potential biomass production. This is equal to 360 EJ.

If only the actual land area can be used for food and biomass production, the global production of biomass fuel becomes much smaller and may vary from nil to 16 * 10^{12} kg biomass dry matter yr^{-1} for respectively the LEI system with moderate and high food demand and the HEI system with a very low food demand. The HEI system in combination with a high food demand results in 9 * 10^{12} kg biomass dry matter yr^{-1} and the LEI system in combination with a low food demand in roughly the same result for biomass production on the actual agricultural area. This is equal to 162 EJ.

If the HEI system is not only applied for food production, but also for the production of biomass fuel, the potential global biomass production becomes largest and may vary from 9 * 10^{12} to 51 * 10^{12} kg biomass dry matter yr^{-1} for respectively the HEI system with a very high food demand and production only on the actual agricultural area and the HEI systems with a very low food demand and use of the potential agricultural area. The HEI system in combination with a high food demand results in 36 * 10^{12} and 16 * 10^{12} kg biomass dry matter yr^{-1} if respectively the potential and the actual agricultural land areas are used.

Table 10. The maximum production o f biomass fuel (10^{12} kg dry matter yr^{-1}) with HEI and LEI systems on the potentially available land areas on this globe (Table 9), assuming HEI or LEI systems for food production on the potential (Pot) and actual (Act) agricultural land areas and different global food demands as based on three population growth scenarios (i.e. low, medium, and high population growth) and three diets (i.e. vegetarian, moderate, and affluent diet).

	Vegetarian diet			Moderate diet			Affluent diet		
System[1] Bio/Food	Low growth	Medium growth	High Growth	Low Growth	Medium growth	High growth	Low Growth	Medium Growth	High growth
L/H_{Pot}	28.00	27.38	26.44	25.20	23.96	22.71	20.84	18.67	16.18
L/L_{Pot}	23.64	22.09	20.22	17.42	14.31	10.89	7.16	1.56	0.00
L/H_{Act}	16.60	16.00	15.20	14.04	12.64	11.28	9.68	7.52	5.12
L/L_{Act}	12.24	10.88	8.68	6.12	2.56	0.00	0.00	0.00	0.00
H/H_{Pot}	51.10	50.01	48.25	46.00	43.73	41.46	38.03	34.09	29.57
H/H_{Act}	30.30	29.20	27.74	25.62	23.07	20.59	17.67	13.72	9.34

[1] L/H_{Pot} = LEI system for production of biomass fuel; HEI system for food production; potential agricultural land area is used.
H/H_{Act} = HEI system for production of biomass fuel; HEI system for food production; actual agricultural land area is used.
L/L_{Act} = LEI system for production of biomass fuel; LEI system for food production; actual agricultural land area is used.

6. Discussion

Results from the study by Luyten were determined by its assumptions. Uncertainties in these assumptions may result in uncertainties in the calculated world food supply and demand and thus in the potential area for biomass production. It was analysed which regions have large land areas that are not needed for food production and can be used for the production of biomass fuel. The potential production of biomass fuel as calculated in this study was compared with the biomass production results from other studies. The arable land areas as calculated in this study were compared with the arable land areas assessed in other studies. The grain yields as calculated in this study were compared with the grain yield observed over the last 40 years. Finally the main effects of climate change and increased carbon dioxide on potentially available areas for biomass production were discussed.

6.1 Major assumptions

Food demand in the future is determined by the population size and the assumed diet. Different diets were defined which covered well the range of consumption patterns from very moderate in a poor society to an affluent pattern in a rich society. Increasing wealth over time results in general in a more luxurious consumption pattern with more meat, and thus in higher requirements for primary products and for land in use for agriculture. The most recent projections from the United Nations (1997) were lower than the previous projections, used in the study by Luyten.

By linear interpolation between the projections for the years 2025 and 2050, the global population sizes became 7586.9, 8835.7 and 10126.0 million people in year 2040 for the low, the medium and the high growth scenario, respectively. This was respectively 2, 6 and 10% lower than the population size assumed in the Luyten study. The average increase in global population is at present 80 million people per year, which according to the scenarios will change to 7.5, 53.1 and 103.0 million people per year between years 2025 and 2050 (Heilig, 1999). This assumes a decrease in fertility which ranges from a very rapid to a much slower decrease. The difference between the population sizes according to the two extreme scenarios strongly increases over time, which may cause a difference in food demand by a factor 1.5 in year 2050.

The potential for food production in the study by Luyten is the product of the area suitable for mechanized farming, the number of growth periods per year and the yield level per hectare. This yield level depends on the production system that was assumed (i.e. HEI or LEI) and on the availability of irrigation water. This results in potential yields that are mainly determined by crop characteristics and weather conditions, water-limited yields that are mainly determined by the amount of rainfall, and nitrogen-limited yields (in the LEI system) that in general are determined by the biological nitrogen supply.

Potential and water-limited yields were calculated for average crop characteristics and average monthly weather conditions. Some of the specific characteristics of crops and of the year to year variability in weather conditions were left out in this procedure. However, this did not affect the results because farmers can be assumed to use cultivars adapted to the specific conditions and because weather variability was averaged out at the regional scale. The nitrogen-limited yield in the LEI system was strongly determined by the nitrogen supply from biological nitrogen fixation. This nitrogen supply was difficult to determine because it depended strongly on management and soil characteristics. If this nitrogen supply was assumed to be two-times as high, this led to a 60% higher maximum global food production in the LEI system (Luyten, 1995). However, if the biological nitrogen fixation was overestimated in this study, which is more probable, the maximum global food production in the LEI system becomes lower. This would result in a smaller area available for biomass production.

From the temperature course over the year at each site the number of growth periods per year was determined, which was a reasonable approach. The area of the land that was suitable for mechanized farming, was calculated from the total land area and the fraction of land that was suitable for mechanized farming. This fraction was estimated on the basis of the soil type and characteristics and the slope gradient. This approach was based on very limited soil information and indicated limitations for the use of the soil and its production level. However, the areas in use for arable farming and for grassland as calculated in this way and as derived from FAO data, were not too different. Hence, this approach worked reasonably well to determine the suitable land areas. It should be considered for the future that soils with present limitations due high groundwater level, salinity, steep slopes, acidity, etc, can be improved by drainage, leaching, liming, terrassing, etc. However, this requires large investments in land reclamation and improvement.

6.2 Levels of food production

The global food production was calculated for two different production systems. In the HEI system crop production was assumed to be maximized, to use a large amount of external inputs and to be realized under optimum management. This means that constraints associated with the current situation with respect to knowledge, infrastructure, economic or socio-cultural conditions, etc. have not been taken into account. Differences in production potential were the result of differences in climate and soil characteristics and not due to sub-optimal management, infrastructure or prices (Luyten, 1995). In the LEI system crop production was realized under optimum management too, but in this system no chemical fertilizer and biocides were applied. Nitrogen was entered in this system mainly by biological nitrogen fixation. This required special crop mixtures or crop rotations. The global food production in this system was very high compared to the actual food production (Table 6). Reasons for this large difference in global food production were given in section 3.5.4. This illustrates that the actual production situation strongly differs from the HEI and LEI systems under optimum management. The application of these 'optimum management' and 'high input systems' at a global scale requires investment in infrastructure, knowledge, education in modern farm techniques, favourable external conditions (i.e prices, market system, government actions and investments), etc., which may require more time than the time period of 50 years in the Luyten study.

The results from the exploratory study by Luyten which assumed that food production in the future occurred under best agricultural practices and that the environmental conditions and crop characteristics mainly determined the crop yields, should be compared with results from other studies, which are more related to the present situation. Such studies extrapolate recent past trends in food production to the future (Brown & Kane, 1994) or predict food production on feasible (as based on expert opinion) changes in land use, yields and trade (Alexandratos, 1996; Rosegrant et al., 1995). Results from such studies should indicate if the optimistic results from the exploratory study by Luyten on the potential for food production and the available area for biomass production may be attainable in the long term, and which factors may threaten the required increase in global food production due to population increase and income rise. This increase in global food production should preferably occur by increase in yield level, as area expansion would require the cultivation of natural and fragile land (Alexandratos, 1996; Bindraban, 1999; IFPRI, 1995) and would limit the area available for the production of biomass fuel.

6.3 Regional differences

The ratio between the food production and the food demand was used to calculate the fraction of the potential agricultural land that may be used for the production of biomass fuel (section 5). These ratios were also determined for 15 regions of the globe by Luyten (1995) and for a minimum, a medium and a maximum food demand (Table 11). This indicates which regions of the world have sufficient land areas for production and export of biomass fuel .

When the HEI system is practised, all regions can produce the food required, even for a high population size and an affluent diet, except for Eastern and Southern Asia (Table 11). South-east and Western Asia and Western and Northern Africa can supply just enough food (ratio above 2). The regions where large areas of land are available for biomass production, are South America, Northern America, Central Africa and Oceania.

Table 11. Ratios between global food production in the future as calculated for the HEI and the LEI systems on the potential agricultural land area, and global food demand as determined for a minimum (vegetarian diet, low population growth), a medium (moderate diet, medium pop. growth) and a maximum (affluent diet, high pop. growth) food demand, as calculated for the 15 large regions of the world (Source: Luyten, 1995).

	HEI			LEI		
Region	Minimum Demand	Medium demand	Maximum demand	Minimum Demand	Medium demand	Maximum demand
South America	89.2	41.7	20.0	30.1	14.1	6.8
Central America	15.6	7.2	3.5	6.8	3.1	1.5
North America	49.3	22.3	10.5	25.0	11.3	5.3
North Africa	13.7	6.0	2.8	8.1	3.5	1.7
Western Africa	16.0	6.4	2.9	6.8	2.7	1.2
Central Africa	83.2	35.6	17.1	29.6	12.7	6.1
Eastern Africa	22.0	9.4	4.3	7.4	3.2	1.5
Southern Africa	31.0	14.8	6.9	14.6	7.0	3.3
Oceania	270.7	126.9	60.6	146.5	68.7	32.8
Southeast Asia	11.8	5.1	2.4	3.8	1.7	0.8
Eastern Asia	5.7	2.6	1.3	3.2	1.5	0.7
Southern Asia	3.7	1.6	0.8	2.0	0.9	0.4
Western Asia	10.5	4.4	2.0	5.6	2.3	1.1
(former) USSR	29.5	14.0	7.0	16.0	7.6	3.8
Europe	13.5	6.4	3.2	6.5	3.1	1.6
World	19.7	8.8	4.2	8.4	3.7	1.8

In the less developed and poor societies where agriculture should be based more on local resources, the LEI system may be applied in the future. This system may be combined with a minimum to medium food demand (in case of higher population growth). In that situation all the regions can supply the food required, except for again Eastern and Southern Asia (Table 11). South-east and Western Asia can supply just enough food. The regions where large areas of land are available for biomass production, are again South America, Northern America, Central Africa and Oceania.

If it is assumed that only the actual agricultural land area is used, the ratio's in table 11 are on average reduced by a factor 1.6 (see Table 8). The ratio's in the different regions may not be reduced to the same extent, being dependent on the suitable but not yet used land area for agriculture. However, it may be concluded that the regions with large areas of land available for biomass production are the same as those mentioned above.

6.4 Comparison with biomass production assessed in other studies

The production of biomass fuel as calculated in this study (Table 10), was compared with th e results from other studies (Table 12). This shows that the production of biomass fuel in this study was relatively high (i.e. 360 EJ) compared to that in other studies, if the potential agricultural land area was used for food and biomass production.

Table 12. Comparison of the global production of biomass fuel, the global land area used for biomass production and the average yield level as determined in a number of bioenergy assessments for year 2100 (source: Hoogwijk et al., 2000) with the results from this study.

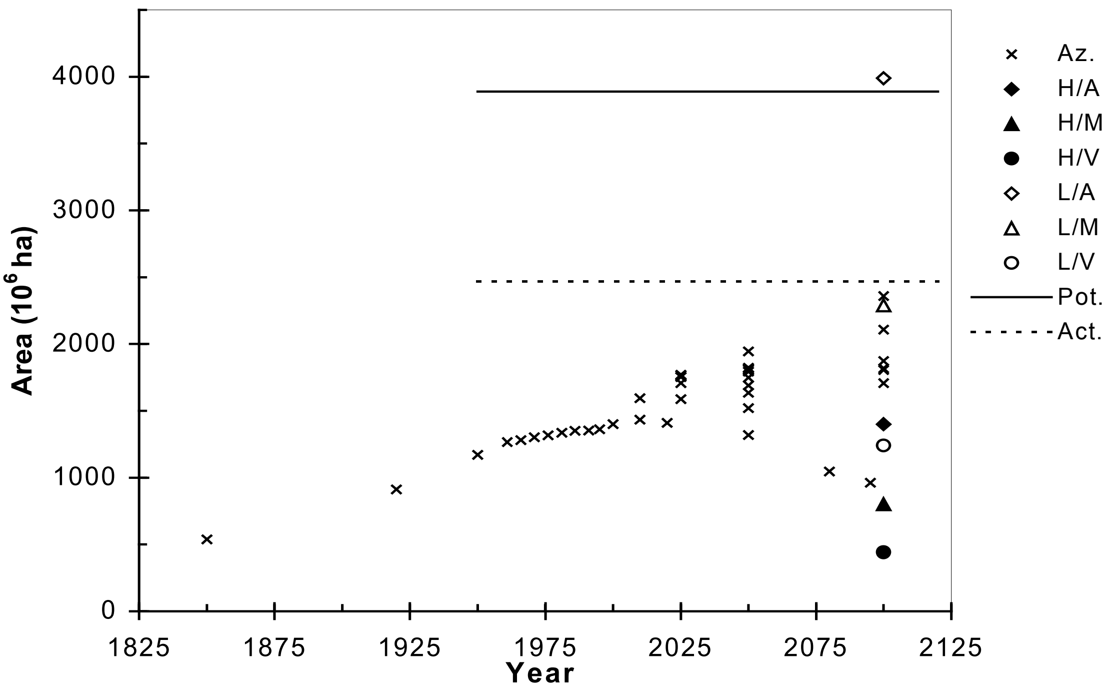
Study[1]	Area (10^6 ha)	(10^3 kg/ha)	Pr (10^{12} kg)	Energy prod. (EJ)
Hall	890	16.7	14.9	268
IMAGE SRES-A1	334	23.9	8.0	107
IMAGE SRES-B1	194	23.7	4.6	62
LESS-BI	572	20.0	11.4	227
LESS-IMAGE	798	9.8[3]	7.8[3]	140
RIGES	429	14.9	6.4	128
SEI/Greenpeace	721	13.9[3]	10.1[3]	181
L/Pot[2]	5000	4.0	20.0	360
L/Act[2]	2250	4.0	9.0	162
H/Pot[2]	5000	7.3	36.0	648
H/Act[2]	2250	7.3	16.4	295

[1] For the meaning of the acronyms, the full references and a review of these studies, see Hoogwijk et al. (2000).
[2] Biomass production assuming a HEI system for food production in combination with a high food demand or a LEI system for food production in combination with a low food demand; L/Pot = LEI system for biomass production and potential agricultural land area used; H/Act = HEI system for biomass production and actual agricultural land area used.
[3] Biomass was calculated from energy content, assuming 18 MJ/kg biomass dry matter.

In that situation the agricultural area was largely expanded and a very large area was used for biomass production. If only the actual agricultural land area was used, the production of biomass fuel was about identical (i.e. 162 EJ) to that in the other studies. However, the yield level was relatively low and the area used for biomass production was relatively large compared to the other studies. The other studies appear to be quite optimistic about the attainable yield level. It was shown (Table 9) that this large land area used for biomass production was only available if a HEI system for food production was applied and became nil with a LEI system for food production (except for a situation with vegetarian diet). If a HEI system was applied for the production of biomass fuel (Table 12), the yield level in the study was still low compared to that in the other studies, but the production of biomass fuel was very high compared to that in the other studies. This was again caused by the large land area used for biomass production.

6.5 Comparison with arable land areas assessed in other studies

The global arable land areas as estimated for the past, as observed over the last 40 years, and as projected for the future in a large number of studies, were given by Azar & Berndes (1999). Figure 1 shows these data in comparison with some results from the present study. To allow such a comparison, the results from the present study were assumed to apply to year 2100. In addition, it was assumed that the arable land areas were 50% of the required total agricultural land areas, as used in the model approach Figure 1.



Global arable land areas in the past and projected in a number of studies for the future as collected by Azar & Berndes (1999; Az.) versus global arable land areas determined in the present study. These arable land areas were calculated as 50% (see Table 5) of the total agricultural land area (H/A = HEI system, affluent diet; L/M = LEI system, moderate diet; L/V = LEI system, vegetarian diet; for the HEI system the population growth was assumed to be low to medium and for the LEI system this growth was medium to high; Pot. = potential arable land area; Act. = actual arable land area).

(Table 5). The required agricultural land area decreased with increasing food production per ha (HEI versus LEI system) and increased with increasing food demand (from vegetarian to moderate to affluent diet). In Figure 1 the potential and the actual global arable land areas (i.e. 50% of total agricultural land area) were included to show the maximum for arable land area, both with and without expansion of the agricultural area.

The areas required for future arable production ranges in the present study from 0.8 à 1.4 * 10^9 ha for the HEI system with moderate to affluent diet to 1.2 à 2.3 * 10^9 ha for the LEI system with vegetarian to moderate diet (Figure 1). Comparison of these ranges of required arable land areas with the arable area projections for year 2100 as collected by Azar & Berndes (1999) shows a good agreement.

Figure 1 also shows that up to the year 2100 sufficient land is available for arable cropping without expansion of the actual agricultural land area (if LEI system combined with affluent diet is not to be expected), even when the LEI system is applied. However this assumes a conversion from permanent grassland to arable land. After year 2100 a shift to the HEI system will be required if expansion of the agricultural land area beyond the present land area is not allowed to prevent cultivation of natural areas.

6.6 Comparison with the actual grain yields

The grain yields on average in the world as calculated in the study by Luyten (1995) were compared with the average grain yields as observed over the last 40 years (Table 13). This shows that the actual grain yields increased rapidly over time. These increases were clearly different between the regions with a small increase in Africa and much larger increases in the other regions.

Table 13. The average yield (kg/ha) of all grain crops in the world and in a number of regions as observed over time (FAO statistical data base) and the future grain yields (air dry)[1] on average in the world as calculated for the HEI and LEI systems in the study by Luyten (1995).

	Yield observed in year					
	1961	1970	1980	1990	1995	1999
World	1353	1765	2161	2759	2751	3036
Africa	809	905	1128	1175	1091	1224
Asia (excl.Russia)	1212	1641	2074	2816	2878	3138
Latin Am.(incl.Carib.)	1272	1533	1798	2087	2545	2844
Western Europe	2150	2787	3891	4743	4987	5528
	Yield calculated					
World	LEI Irrigat.	LEI Rainfed	HEI Irrigat.	HEI Rainfed		
	4610	2500	16270	6670		

[1] Grain yields are given as air dry biomass in the statistics. As in the study by Luyten yields are given in biomass dry matter, these yields are divided by 0.88 (i.e. dry matter content in air dry grains).

The grain yields were calculated in the present study for both the HEI and the LEI system with and without irrigation. If the irrigated area in the future is estimated at 25% (Table 7: at present 18% of arable area), the average yield for the HEI and the LEI systems becomes respectively 9100 and 3000 kg/ha in grains (Table 13). The global average grain yield in year 1999 was already identical to the yield for the LEI system and the average yield in Western Europe and the USA approached the yield for the HEI system.

The average increase in grain yield was calculated for the world and for a number of regions (Table 14). The increase in Africa was very small and was almost nil over the last 10 years. In the other regions and in the world as a whole the increase was on average 3 to 4% (of the yield in year 1961) per year over the last 40 years.

In the last 10 years the global increase became smaller (i.e. 1% per year), although the absolute increase was not much reduced. The strongest yield increases in the last 10 years were observed in Latin America and Western Europe. Table 14 may be used to make an estimate when at the global scale the average yield level for the HEI system (Table 13) can be attained.

Table 14. Increase in average yield of all grain crops in the world and in a number of regions as observed over time (FAO statistical data base).

	Increase (period 1961-1999)		Increase (period 1990-1999)	
	(kg/ha/yr)	% of yield in 1961	(kg/ha/yr)	% of yield in 1990
World	44	3.3	31	1.1
Africa	11	1.3	5	0.5
Asia (excl.Russia)	51	4.2	36	1.3
Latin Am.(incl.Carib.)	41	3.3	84	4.0
Western Europe	89	4.1	87	1.8

6.7 Effects of increasing carbon dioxide and climate change on agricultural production

Agricultural production is greatly affected by climate. Hence, any changes in climate in the future which may result from increasing concentrations of greenhouse gases in the atmosphere, could have dramatic consequences for the agricultural yield potential. Weather variables, but in particular temperature and rainfall that are of main importance for crop growth, are expected to change in the future. Global temperature may rise by 2 ^{0}C in the coming 80 years (Barrow & Hulme, 1997), which may cause a faster development of crops and a shorter growth period. This might result in a lower yield level, but the annual production per year may stay the same by management adaptation: 1. by growing crops with a longer growth period; 2. by growing more crops per year. In cooler areas the length of the growing season (above minimum temperature for growth) may increase, which gives the possibility for growing more crops or growing crops over a longer period, yielding a higher production per year. Rainfall is also expected to change in the future. This may result in regions where dry periods become longer and drought effects on yield become more severe (e.g. North Africa and Southern Europe). However, the mean amount of rainfall on this globe is expected to increase, and only its distribution over the globe may change. This change in rainfall may cause severe effects on food production at the regional scale. However, it is not to be expected that the changes in both rainfall and temperature in the future have negative effects on the global potential for food production and thus on the area that is potentially available for the production of biomass fuel.

The atmospheric CO_2 concentration increases by about a half percent per year. This increase in atmospheric CO2 results in considerable increases in growth rate and yields of most crops (Cure & Acock, 1986; Idso & Idso, 1994). For example in year 2060, when the CO_2 concentration is expected to be 40% higher than the present concentration, the yields for most crops will be 15 to 20% higher. In case of water shortage this yield increase may be even larger, but in case of nutrient limitation, this yield increase will be smaller.

The impacts of climate change and increased CO_2 on future crop production were calculated to be positive in most agricultural systems (Adams et al., 1990; Curry et al., 1990, 1995; Easterling et al., 1992a,b; Wolf & Van Diepen, 1994, 1995). This means that the potential for biomass production in the future becomes larger, if these impacts of increased CO_2 and climate are taken into account.

7. Main conclusions

- In the highly developed and wealthy societies the High External Input (HEI) system of agriculture, an affluent diet and a low to medium population growth are to be expected. In that situation 40% of the global potential agricultural area is needed for food production and the remaining area can be used for other purposes, such as production of biomass fuel.

- In the less developed and poor societies agriculture should be based more on local resources and the Low External Input (LEI) production system may then be applied in the future. This may be combined with a medium to high population growth and a mainly vegetarian diet. In that situation also 40% of the global potential agricultural area is needed for food production and the remaining area can be used for other purposes.

- The fraction of the area that can be used for other purposes, such as production of biomass fuel, becomes much smaller than that given in the previous points, if only the actual agricultural land area is used and area expansion is assumed to be nil to prevent the cultivation of natural areas. In that situation 60% of the global actual agricultural area is needed for food production with both the HEI and the LEI system in combination with population growth and diets mentioned in the previous points.

- The maximum production of biomass fuel can be calculated as the product of the available areas (see previous conclusions: $5 * 10^9$ ha if the potential agricultural land areas can be used) and the biomass yield per hectare. It can be assumed that the production of biomass fuel is done without irrigation and in a LEI system, and that the harvest index of the biomass crop and thus the global mean yield level is roughly the same as that calculated for grassland: 4000 kg dry matter ha^{-1} yr^{-1}. This results in a maximum production of biomass fuel of $20 * 10^{12}$ kg dry matter yr^{-1}, which is equal to 360 EJ. If it is assumed that biomass production is done with a HEI system, the maximum production increases to $36 * 10^{12}$ kg dry matter yr^{-1}.

- The production of biomass fuel becomes much smaller if only the actual agricultural land area is used (see point 3: roughly $2.2 * 10^9$ ha available for other purposes). If the biomass production is done without irrigation in a LEI system, it becomes $9 * 10^{12}$ kg biomass dry matter yr^{-1}, which is equal to 162 EJ. If a HEI system is applied for biomass production, the production increases to $16 * 10^{12}$ kg biomass dry matter (i.e. 288 EJ).

- No agricultural land area is available for the production of biomass fuel if the actual agricultural land area is used, a LEI system is applied for food production, and a moderate diet is assumed.

- The production of biomass fuel as calculated in this study, corresponds reasonably well with that calculated in other studies. However, the yield level in this study is relatively low and the land area used for biomass production is relatively large.

- The range of arable land areas projected in a number of studies for year 2100 (collected by Azar & Berndes, 1999) corresponds quite well with the range of arable land areas determined in the present study.

- The actual grain yields increased by 3% per year on average in the world over the last 40 years and attained in year 1999 the same global average grain yield level as calculated for the LEI system.

- Results from the study by Luyten were determined by its assumptions. A different assumption may result in a different ratio between global food production and global food demand and thus in a different agricultural area that is potentially available for production of biomass fuel. Factors that appear to be important and require further study, are: 1. Population size that may vary by a factor 1.5 in year 2050; 2. Biological nitrogen supply that strongly determined the global food production in the LEI system, was uncertain; 3. The fraction of land that was suitable for mechanized farming, was estimated on the basis of very limited information: soil type and characteristics and the slope gradient; 4. Global food productions in the LEI and in particular the HEI system are very high compared to the actual global production, and they require 'optimum management' and 'high input systems' at a global scale, which may need more time than the 50 years in the Luyten study.

- Crop residues from arable crops are used for many important purposes (such as animal feeding and maintaining soil structure and soil fertility), but a small fraction of the potentially available amount of residues may result in an important supply of biomass fuel.

- Results from studies that extrapolate recent past trends in food production or predict production on feasible changes in land use, yield and trade should be used to test if the optimistic results from the study by Luyten on the potential for food production and the available area for biomass production may be attainable in the long term.

- The regions where large areas of land are potentially available for the production of biomass fuel, are South America, Northern America, Central Africa and Oceania, however, only in case the HEI or the LEI production system is practised.

- Future climate change may have important effects on food production at the regional scale, however, its effect on global food production and thus on the available area for biomass production is probably negligible.

- Increase in atmospheric CO_2 results in considerable increases in growth rate and yields of most crops, which for year 2060 were estimated to be 15 to 20% higher. This means that the available area for the production of biomass fuel in the future and thus the potential biomass production become larger.

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ANNEX 4

SUBPROJECT 3:

CONTRIBUTION TO THE FORMULATION OF SUSTAINABILITY CRITERIA FOR LARGE SCALE INTERNATIONAL TRADE IN BIOMASS FOR ENERGY

UU-STS

Contribution to the formulation of sustainability criteria for large scale international trade in biomass for energy

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1. Introduction

Import of (energy from) biomass in the Netherlands is considered because the use of bio-energy instead of fossil fuels could reduce greenhouse gas emissions of the Netherlands. Imported (energy from) biomass would be accounted as renewable energy. Insights from previous studies and reviews show that even intercontinental transport of biomass is not expected to be prohibitive both in terms of costs as well as energy use of the transport chain. A conclusion is therefore that biomass resources from other parts of the world may be economically and efficiently utilised in countries like the Netherlands in order to prevent the use of fossil fuels.
However, the carbon neutral character of biomass is not the only relevant criterion for a *sustainable* energy system. Sustainability criteria are not limited to ecological dimensions (such as emissions to air, other environmental impacts and biodiversity) but include economic and social dimensions as well. Large scale biomass import may be a particular sensitive option in this respect. Substantial contributions to the energy supply will require large land areas (see box: Land use for energy production). Claiming large land surfaces abroad for energy purposes may result in serious repercussions with respect to the local agriculture, economy and environment. In case large scale bio-energy import does not meet a set of stringent criteria covering ecological, social and economic aspects, the societal resistance against this option may become prohibitive. ("Greenpeace blocking bio-energy bulk carriers in Rotterdam harbour").

The main objective of this paper is to give an outline of (potentially) relevant criteria that should be met to guarantee a sustainable bio-energy trade chain. In order to do so, general criteria mentioned in the literature regarding energy systems and sustainable development will be translated to more detailed concrete parameters that apply to bio-energy systems and import chains. In total, such a set of criteria should provide a framework for appraisal of bio-energy trade chains. This framework will set a standard for both qualitative and quantitative demands for bio-energy trade chains.

LAND USE FOR ENERGY PRODUCTION
Biomass production requires land. Relatively conservatively, the productivity for a perennial crop (like Willow, Eucalyptus or Switchgrass) lies between 8 - 12 tonnes dry matter per hectare per year. The heating value of dry clean wood amounts about 18 GJ/tonne (LHV). This is gross energy yield, and the energy inputs for cultivation, fertiliser, harvest, etc, amounting about 5%, should be deducted). One hectare can therefore produce about 140 – 200 GJ/ha per year. 1 PJ would require 5,000 - 7,000 ha.
The amount of fuel needed to fire a 600 MWe base load power plant (7000 full load hours) with 40% efficiency is 38 PJ per year. This would require 190,000 - 260,000 ha.
Supplying one quarter of the world's current energy consumption, i.e. about 100 EJ, would require about 500 - 700 million hectares (Mha), which is about half of the present worldwide land use for agriculture and equals 4% - 5% of the total world land surface. The total land surface of the Netherlands amounts 3.4 Mha, and the present Dutch energy demand is about 3000 PJ. Covering one quarter of the national energy demand with (imported) biomass would require about 4 – 5 Mha.

2. General sustainability criteria

A sustainable energy system should meet a diverse set of criteria with ecological, social and economic dimensions. The meaning and operationalisation of ‘sustainable’ has been widely debated, but is still hard to implement to concrete technologies or activities. Within United Nations frameworks ‘sustainability’ has been broken down to a number of more concrete criteria which are relevant for energy systems. This list of criteria is discussed by [Turkenburg] and is given below:

Clean: GHG neutral or almost GHG neutral; all other (major) environmental standards should be fully met (acidifying emissions, particulates, ozone, water pollution, eutrophication, chemical, soil quality, nature preservation, etc.)

Safe: Strict safety standards should be met.

Efficient: Minimize the need for raw materials, resources, land-use, storage capacity.

Reliable: Supply disruptions should be minimized and should at least meet current NW European standards or higher. This criterion applies to the technology (conversion, distribution) but also primary energy sources (e.g. variation in biomass supply; diseases, fires, etc.). No over dependency on limited set of suppliers.

Competitive: Costs of energy *services* should be minimized (sustainable economic development); includes R&D trajectories.

Long term perspective:
Potential of the option should be sufficient to justify investments in R&D, infrastructure, etc. (land-use on longer term, CO2 storage capacity, fossil fuel reserves).

Acceptable for society:
Options should meet societal needs, constraints and preferences.

Prevent ‘lock in’:
Options should not block other desirable developments (e.g. other supply routes based on renewables), infrastructure not needed on longer term.

Contribute to industrial development and employment:
E.g. not a full dependency on energy imports, benefits for regional/national industries (compare macro-economic distribution of value added and employment generation), valuable (compare energy farming with gas exploration)”

When considering bio-energy trade chains a few general aspects should be kept in mind.

- Biomass production systems (or resources) are extremely diverse. Productivity, economics and ecological impacts are strongly determined by local physiological and socio-economic conditions. The way criteria are implemented or the relevance of criteria as such can therefore differ strongly depending on local conditions (consider forestry in Sweden versus Eucalyptus production in Mozambique).
- Bio-energy trade chains can have many forms. Energy carriers imported can vary from untreated biomass, to pre-treated biomass (e.g. dried, sized compacted; briquettes), intermediate energy carriers (such as bio-oil, charcoal) that require some conversion in the biomass producing country, or gaseous and liquid fuels that can be marketed directly (such as hydrogen, methanol, ethanol and synthetic hydrocarbons). On shorter distances (e.g. 1000-1500 km) electricity generated by biomass conversion can be considered. This implies that the location where partial or full conversion takes place is a major variable for economic (investments), social (e.g. jobs) and ecological (emissions and residues produced) for both importing and exporting country.

3. Application of sustainability criteria to bio-energy trade chains

1. Clean

This criterion includes both environmental standards (e.g. related to emissions) as well as ecological impacts.

Environmental aspects regarding biomass production systems:

- prevent impoverishment of the soil. Nutrient balance should remain in equilibrium. Ashes (trace metals, etc.) should be fed back to the biomass production area's.
- Prevent nutrient leaching up to stringent groundwater quality standards and protection of nearby ecosystems.
- Use of pesticides should be minimized and meet strict standards in terms of water quality protection, protection of human health, etc. Alternatives for pest control (e.g. biological methods, genetically engineered pest resistant crops) should not result in harmful effects to ecosystems.

- Emissions to air originate partly from crop production operations and transport. Minimization should be strived for. Emissions to air of conversion facilities should preferably meet strict (NW European) standards. Strong differences in emission standards between countries may result in unlevel playing field for conversion facilities. Similar reasoning holds for other emissions potentially related to conversion steps, like production of waste water and production of solid waste streams (if any).

Ecological aspects regarding biomass production systems

- By all means no nature areas should be threatened by biomass production for energy.
- Soil quality should at least be maintained (in terms of structure, organic matter content, fertility, etc.) and preferably improved (higher organic matter content, increasing humus layers, improving water retention. This pleads in general for perennial crops.
- Prevention of erosion (or improve soil protection).
- Prevent depletion of water resources. This explicitly includes both surface water and groundwater resources. By no means should large scale biomass production conflict with water consumption of agriculture, use in urban areas or limit the water availability for nature areas such as forests, wetlands, etc. This is a key aspect in particular for more arid regions in the world. Selection of suited crops and for example not considering irrigation and accepting lower productivities may play a key role in setting up sustainable biomass production systems.
- Maintain or improve local and regional biodiversity: landscape planning and choosing viable percentages for land cover with production crops will be major tools to prevent a loss of biodiversity or monotonous landscapes. Reserving a percentage of land in biomass production zones for e.g. natural vegetation and mixing with other crops could even lead to improvements with respect to biodiversity and variation in landscape. All of this will be strongly determined by local conditions.

In total much can be learned from FSC (Forest Stewardship Council) criteria for sustainable forestry practice.

2. Safe

Strict safety standards should be met. Hazards and risks regarding large scale bio-energy trade chains are for example:

- Accidents during biomass production, in particular harvesting. Forestry methods should included strict safety regulations to prevent injuries and casualties.
- Minimize the amount of (road) traffic. Per amount of energy, raw biomass is a bulky fuel. Road transport may lead to increases in traffic injuries and casualties on a local level. Logistics should be organized in an optimal and responsible way.
- Prevention of spreading plant diseases by importing raw biomass material. Correct certification and control procedures should be applied.
- Prevention of spreading of (genetically) modified plant species that may dominate local species.

3. Efficient

Efficiency of the total bio-energy trade chains is extremely relevant for various other criteria. In the first place high overall chain efficiencies minimize the amount of land required for a desired energy service. Therefore, bio-energy trade chains should be as efficient as possible (which may result in a preference for more expensive energy carriers when the amount of land needed is minimized). Generally a high efficiency reduces costs and increases productivity. Similar reasoning generally holds for environmental impacts.

In case of conversion of biomass to energy carriers in the producing country, the use of waste heat or other energy carriers than exported (e.g. electricity) could contribute to high overall chain efficiencies.

However, efficiency also applies to the efficiency of using biomass in reducing GHG emissions. If biomass can be utilised in the local/regional energy system for replacing fossil energy carriers, the costs per tonne of carbon emission avoided may be lower than when exported. Furthermore, saving on international transport and potentially replacing inefficient local fossil fuel fired (power) conversion units, may result in higher GHG emission reduction per unit of available biomass compared to the situation that biomass is used in an energy system where it replaces (very) efficient capacity.

4. Reliable

Supply disruptions should be minimized. This criterion applies both to the technology (conversion, distribution) as well as primary energy sources (e.g. variation in biomass supply; diseases, fires, etc.). Specific risks that may threaten the reliability of biomass supplies may be:

- Large scale outbreak of pests and diseases.
- Large scale (forest) fires (those may also posse a serious environmental hazard).
- Climatic fluctuations, lowering yields or destroying harvests.

- Over dependency on limited set of suppliers should be prevented. Large scale import of bio-energy may therefore preferably be organized by choosing a wide range of supplying areas and countries.

5. Competitive
Costs of energy *services* should be minimized (sustainable economic development); includes R&D trajectories. Much depends on the costs of major alternatives to reach emission reductions as well.

Also, the competitiveness of using biomass in the (potential) exporting country plays a major role in decision making. This becomes very apparent when emission trading (or flexibility mechanisms as CDM in general) becomes internationally accepted as a means to reduce GHG emissions.

6. Long term perspective
The long term perspective of large scale import is a particularly complex matter. Many key development parameters of potential exporting countries will change over time. Examples are:
- Growth of the energy consumption of the exporting country, increasing the demand for either indigenous of imported energy carriers. Depletion of national reserves (oil, gas) can be a factor in itself.
- Growth of the demand for food. In general the demand for food products and protein rich food products is likely to increase. This will increase the demand for primary agricultural production.
- Development of the agricultural and forestry sector. Modernization and rationalization in the agricultural and forestry sector can lead to higher productivities, potentially decreasing the demand for land. The other way around, unsustainable agriculture may deplete water and land resources and therefore reduced the amount of productive lands.
- Growing demand for biomass for materials and other (non-energy) commodities which are more profitable than energy applications.
- More stringent GHG emission targets. On the longer term, pressure on countries to reduce GHG emissions is likely to increase. This may increase the indigenous demand for GHG neutral energy carriers like biomass, depending on the competitiveness of bio-energy versus alternatives.

Potential of the option should be sufficient to justify investments in R&D, infrastructure, etc. (land-use on longer term).

7. Acceptable for society
This criterion may, particularly on the shorter term, be a key aspect. Ensuring that all other ‘sustainability criteria’ are met will certainly reduce potential societal resistance. But preferences as such may become a barrier against bio-energy as such. Major potential societal barriers are:
- Prevent competition with local land-use and crop production. One major risk regarding bio-energy export may be a relative higher economic benefits from land compared to (traditional) food crops. This may lead to loss of jobs for farmers, reduction of local food production and increasing poverty. Induced land-use by farmers moving to poorer soils may lead to large scale unsustainable agriculture.
- Production (and conversion) of biomass locally does not contribute to the local/national economy due to foreign investments, companies and even labour that run the total production system.

8. Prevent 'lock in'
Options should not block other desirable developments (e.g. other supply routes based on renewables), infrastructure not needed on longer term. With respect to bio-energy trade this may occur in exporting countries that would only consider bio-energy export on the short term, while on the longer term biomass resources are needed in the country itself. Also for an importing country this may be relevant when built conversion capacity to be supplied by imported biomass cannot be supplied with feedstock at desired price levels.

Prevention of this potential problem may be obtained by producing biomass that can be sold for other used than energy (e.g. pulp, construction) as well.
Conversion capacity should be flexible for various fuels and also be usable for fossil fuel firing as a back-up (e.g. including CO2 removal and storage).

9. Contribute to industrial development and employment
In particular relevant for biomass production systems in developing countries: local labour and skills should be usable in production systems (compare e.g. plantations run by foreign companies versus biomass production areas which are operated by local farmers that supply to a biomass market). The same could be applied to conversion technologies used on a local level. Could locally available (produced) technology be used?

Strive for additionality
In ideal case, bio-energy projects abroad should not only live up to 'minimum' levels of safety, environmental and economic performance, but preferably also result in additional benefits for the biomass producing country. In this context the principle of additionality could be applied. Additionality is also incorporated in AIJ (Activities Implemented Jointly) projects which currently serve as test cases for potential large scale implementation of CDM and JI projects.

Major benefits regarding biomass production and export could e.g. obtained at:
- use of degraded land, where biomass production also results in ecological benefits like restoration of soils, improve water retention, increase carbon storage and increase wood availability for the local population
- in total development schemes where bio-energy production systems result in benefits for the traditional agricultural sector as well; e.g. additional income of biomass export is invested to modernize local agriculture leading to higher productivities, reduced land use and improved farmer incomes. Altogether, synergy between biomass production for energy and the agricultural sector should be achieved. Agroforestry projects and multifunctional land-use and multi-output production systems could be ways in general to achieve such synergy
- production of biomass by countries where biomass production would strengthen the local/national economy in terms of both foreign currency, foreign investment and local job generation
- countries where setting up a biomass industry would result in improvements of the national energy system as well.

ANNEX 5

SUBPROJECT 4

CASE STUDY NICARAGUA

UU-STS

Sustainable production of biomass in Nicaragua for export to the Netherlands: a case study

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Sustainable production of biomass in Nicaragua
for export to the Netherlands: a case study

Contents

1. Background

This document is one of the background reports produced within the framework of the GRAIN (Global Restrictions on biomass Availability for Import to the Netherlands) project. This project aims at assessing the maximum world wide availability of biomass in the context of possible potential large scale import of biomass to the Netherlands in the future. In order to illustrate the meaning of such an import, in this report we undertook a case study on a potential future exporting country. The main objective of undertaking this case study was to assess the feasibility of having a low cost supply of biomass that still meets basic criteria of sustainability.

As a case country we focus on Nicaragua. Nicaragua is chosen since it has many typical characteristics of a developing country, and since energy crops are already cultivated here commercially. Moreover, in most studies, as analysed in another GRAIN background report [1], developing countries, especially those in Latin American, are expected to become the major producer of energy crops, if biomass energy is to play a large role in future global energy supply. The suitability of Nicaragua as a case country for bioenergy led to a number of in-depth studies undertaken during the last years [2-9]. This enable providing a compact overview, within the limited timeframe of this study, of aspects that are important to consider when importing biomass.

The focus in this study is on energy crops since this potential biomass resource is expected to play a major role if future biomass supply grows to high volumes. Moreover, although there are relatively cheap biomass residues available in Nicaragua, the amount is relatively limited [7, 10]. To a large extend these resources are already locally used for energy purposes (mainly in the sugar mill industry). This is expected to be the case in the future as well.

One of the reasons why Nicaragua was chosen, as mentioned above, is that there is already commercial (unsubsidised) experienced with energy crops for electricity generation in this country. Two sugar mill started planting eucalyptus about 10 years ago in order to complement the supply of bagasse to their CHP plants with an off-season fuel. The San Antonio sugar mill, the largest in the country, is expected to start this year with delivering electricity to the national electricity grid throughout the whole year, based on bagasse during the sugarcane season (about 6 months) and cultivated eucalyptus during the rest of the year. Eucalyptus (camaldulensis) has been selected as the most suitable crop for multi purpose use in Nicaragua during a 10 year forestry project in Central America [11].

In this case study we focus on the production of biomass as an energy crop in Nicaragua. Therefore, we do not implement a full chain analysis including conversion and end-use. This has been done in previous assessments [12, 13].

In the report, we first summarise the sustainability criteria that have been mentioned in another GRAIN background report and explain how these criteria are dealt with in this report. Thereafter, we present a short country profile of Nicaragua. This is followed by an (largely quantitative) analysis of the costs, environmental impacts and socio-economic impacts. We shortly go into some aspects regarding safety and reliability of the supply. After this, we illustrate what it would mean for a country like Nicaragua to produce a significant amount (20 PJ) of wood fuel for export purposes. Finally, we come up with some discussion points and final conclusions.

2. Sustainable biomass energy production

In one of the reports resulting from the GRAIN project, an overview has been made on guidelines for the sustainability of biomass energy supply [14] . A sustainable energy system should be (1) clean, (2) safe, (3) efficient, (4) reliable, (5) competitive, (6) have long term perspectives, (7) be acceptable for society, (8) prevent “lock-in”, and (9) contribute to industrial development and employment.

In Section 4.1. we first deal with the question whether the production of biomass in Nicaragua is competitive (Criterion 5). A definitive answer to this can only be given on the basis of a full chain analysis, though. Here we limit ourselves to the cost of the production of the biomass including local transport. As an indication, we add costs for transport of wood and converted fuel to the Netherlands and costs of local conversion and conversion in the Netherlands. After this, we analyse environmental impacts and resource use (Criteria 1 and 3) of the cultivation of energy crops in Nicaragua. This is followed by an assessment of socio-economic impacts, employment generation and distribution of income. This covers Criteria 7 and 9. Finally, in a more qualitative way, we shortly analyse Criteria 2 and 4. Criteria 6 and 8 are general criteria that apply to the whole energy system and can not be analysed regarding a specific case study on the production of biomass. Therefore, in this study these criteria were left out of consideration.

3. Nicaragua: a country profile

In order to get a better insight in the type of country that Nicaragua is, Table 1 shows some important country characteristics for Nicaragua as compared to the Netherlands.

Population density is about a factor 10 lower in Nicaragua as compared to the Netherlands. Population growth in Nicaragua is much higher though. The total land surface of Nicaragua is about three times as large than that of the Netherlands. The present percentage of arable land is higher in the Netherlands (27% versus 20%). The amount of arable land in Nicaragua has almost doubles during the last two decades. On the other hand, deforestation has been very large in Nicaragua. In 1990 the total forest cover of Nicaragua was about 64 thousand km^2 (about 52% of the total land area). In 5 years time this decreased with about 8 thousand km^2 down to 56 thousand km^2 in 1995 [15]. This means an annual decrease of about 2.5% of forest cover.

In absolute terms the GDP of the Netherlands is over a factor 200 higher than that of Nicaragua. On a per capita basis and corrected for purchasing power parities, this difference is still over a factor 10. On top of the low average income in Nicaragua, the distribution of this income is also less equal than in the Netherlands. The richest 20% of the population earns about a factor 13 more than the poorest 20%; in the Netherlands this is about a factor 6. The unemployment rate (1997 value) was about a factor three higher in Nicaragua as compared to the Netherlands. Notable as well is the negative trade balance of Nicaragua, where imports are about twice the export. In the Netherlands there is a small positive balance of payment. Nicaragua is rated as a country with a high investment risk, whereas the Netherlands is considered to have a very low investment risk.

The average Nicaraguan consumes about 5 times less energy and emits about 15 times less CO_2 than the average Dutchman. The total installed electricity generation capacity in 1997 in Nicaragua was about 350 MWe as compared to about 14600 MWe in the Netherlands [16, 17]. Nicaragua has hydro and geothermal power as their only indigenous energy source. At present these sources together constitute almost 40% of the total amount of electricity generated [18] (the rest of the electricity is generated from imported fuel oil).

Table 1. Basic physical, economic and energy related data on Nicaragua with the Netherlands as a reference [15, 19].

	Dimension	Nicaragua	the Netherlands
Physical data			
Land area	10^3 km^2	121	34
Arable land	10^3 km^2	24	9
Population	10^6 person	4	16
Population growth	%/yr	2.2	0.2
Population density	Person/km^2	39	463
Economic data			
Total GDP	10^9\$	2	389
GDP growth 1997-1998	%/yr	6	3
GDP per capita (PPPs)[a]	k$/person	2	22
Inequality of income[b]	-	13	5.5
Unemployment	%[c]	13	4
Balance of payment[d]	%	46	112
Real interest rate	%/yr	7.7	3.5
Investment climate[e]	-	52	86
Energy related data			
Total energy use	EJ/yr	0.2	3.1
Energy use per capita	GJ/person/yr	39	197
Growth in energy use	%/yr	2.7	1.5
CO_2 emission per capita	tonne/person/yr	0.6	10

[a]Purchasing power parities (PPPs) provide a standard measure allowing comparison of real price level between countries. The PPP conversion factors considered here are derived from price surveys covering 118 countries by the International Comparison Programme (ICP).
[b]This is expressed as the ratio between the total income of the richest 20% of the population and the total income of the poorest 20% of the population.
[c]Unemployment is expressed as a percentage of the total labour force.
[d]The balance of payment was calculated as the export divided by the import.
[e]The PRS Group's International Country Risk Guide (ICRG) collects information on 22 components of risk, groups it into three major categories (political, financial, and economic), and converts it into a single numerical risk assessment ranging from 0 to 100. Ratings below 50 are considered very high risk, and those above 80 very low risk.

Table 2 shows some country specific characteristics that have a direct relation with the cost of energy crops. The main reason for the high value of the minimum required internal rate of return (IRR) is the relatively high investment risk in Nicaragua (see Table 1) Land rental costs are almost a factor 10 lower in Nicaragua as compared to the Netherlands. The difference between the Netherlands and Nicaragua is even more extreme with respect to low level labour costs, about a factor 30. This leads to the use of more labour in energy crop cultivation in Nicaragua, e.g. in planting, weeding and harvesting. Because of higher solar radiation and a growing season that is not limited by temperature, the maximum potential yield of trees (closed canopy) in Nicaragua is over 2 times as high as in the Netherlands. However, water-limitation is important in Nicaragua, since precipitation is seasonal, whereas in the Netherlands water-limitation was found to be negligible [20]. The estimated actual yield on the short term is only 25% higher in Nicaragua, resulting from the assumption of better management in the Netherlands. This was based on experiences with food crops and on existing eucalyptus plantations in Nicaragua [2, 20].

Table 2. Comparison of the most important cost items for energy crop cultivation in Nicaragua as compared to the Netherlands [2, 3, 21-24].

	Dimension	Nicaragua	the Netherlands
Economic data			
Discount rate	%/yr	20	5
Cost of land rental	$\$.ha^{-1}.yr^{-1}$	47	400
Labour cost; low level	$/day	2.2	83
Cost of tractor	$/hr	11	20
Energy crop yield[b]			
Maximum potential yield	$tonne_{0\%}.ha^{-1}.yr^{-1}$	42	18
Average water-limited yield	$tonne_{0\%}.ha^{-1}.yr^{-1}$	26	18
Estimated actual yield	$tonne_{0\%}.ha^{-1}.yr^{-1}$	13	10

[a] "-" means "not available".

[b]The potential yield and the water-limited yield as mentioned here are for a closed canopy. The reduction to actual yield results from loss in light interception during when the canopy is not closed (i.e. after planting and after the harvest) and from nutrient limitation, competition with weed and possibly pests and diseases.

4. Cost of energy crops from Nicaragua

4.1. Cost of energy crop cultivation in Nicaragua

Here we present a detailed cost calculation of the cultivation and transport of eucalyptus in Nicaragua. Table 3 presents the most important parameters that were used in the calculation.
A full overview of all data input was presented by Van den Broek [3].

Table 3. Main assumptions in the cost calculation for the cultivation of eucalyptus in Nicaragua.

Parameter	Value	Unit[a]
Interest rate	11	%
Internal rate of return	20	%
Labour cost low	2.2	$/day
Labour cost medium	4.0	$/day
Labour cost high	23	$/day
Land cost	47	$/ha.yr
Cost for plant breeding	1.6	¢/plant
Yield eucalyptus	13	$t_{0\%}$/ha.yr
Area not suitable	20	%
Range of tractor cost	6.5-13	$/hr
Price chainsaw	425	$
Capacity chainsaw	27	m^3_{solid}/day
Cost truck combination	17.2	$/hr
Range average distance	15-42	Km
Fuel reserve needed	10	%

[a]All dollars are US dollars of 1997

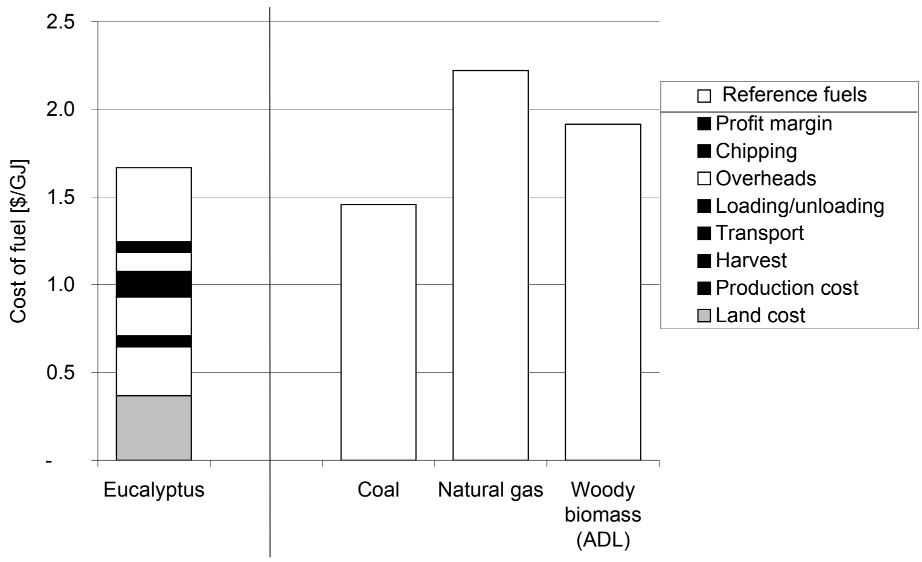

Figure 1. Cost of eucalyptus in Nicaragua at the plant gate or at the harbour at the pacific coast. As a reference costs are presented of coal and natural gas in the Netherlands and of wood as calculated by ADL [13].

Production of eucalyptus (including local transport) is relatively cheap in Nicaragua, about 1.7 $/GJ_{LHV}$ (see Figure 1). It is just below previous estimations on costs of eucalyptus plantations by ADL [13] and in between the price of coal and natural gas in the Netherlands. When comparing these costs with cost estimates for energy crop cultivation in the Netherlands, the difference is large. In the Netherlands the lowest cost option (cultivation of hemp on rotating set-aside land) costs about 5 $/GJ [25].
Willow cultivated by a company on rented land costs about 8 $/GJ. Replacing wheat cultivation or cultivating willow on bought land would is expensive [25].

Although land costs are relatively low in Nicaragua, less than 50 $.ha^{-1}.yr^{-1}, they still compose almost 25% of the fuel cost. A comparable contribution can be found with the profit margin. This is the margin that the company that plants the eucalyptus earns over its investment, on top of the interest it has to pay (illustrated by the gap between the interest rate of 11% and the minimum required internal rate of return of 20%; see Table 3). The bare production costs for eucalyptus (without profit and land costs) is just below 1 $/GJ.

The yield as mentioned in Table 3 was estimated on the basis of the crop growth model SILVA [2] , making use of existing experience with eucalyptus plantations in Nicaragua. As is shown in Figure 2, the cost of eucalyptus is heavily influenced by the yield: a 50% lower yield (6.5 tonne$_{0\%}$.ha^{-1}.yr^{-1}) would lead to a cost of about 2.7 $/GJ instead of the 1.7 as shown in Figure 1, meaning a rise of about 60%. Starting from the yield of 13 tonne$_{0\%}$.ha^{-1}.yr^{-1}, a 50% yield increase would lead to a cost of about 1.3 $/GJ, a decrease with about 20%. Experiences in practice have already shown that in areas with less rain, average yields can go below 10 tonne$_{0\%}$.ha^{-1}.yr^{-1} [2]. Moreover, it is shown that land costs are important in the cost calculation of willow. If land cost would double, the cost of eucalyptus would become about 2.2 $/GJ. Without land costs, the cost of eucalyptus production is 1.2 $/GJ.

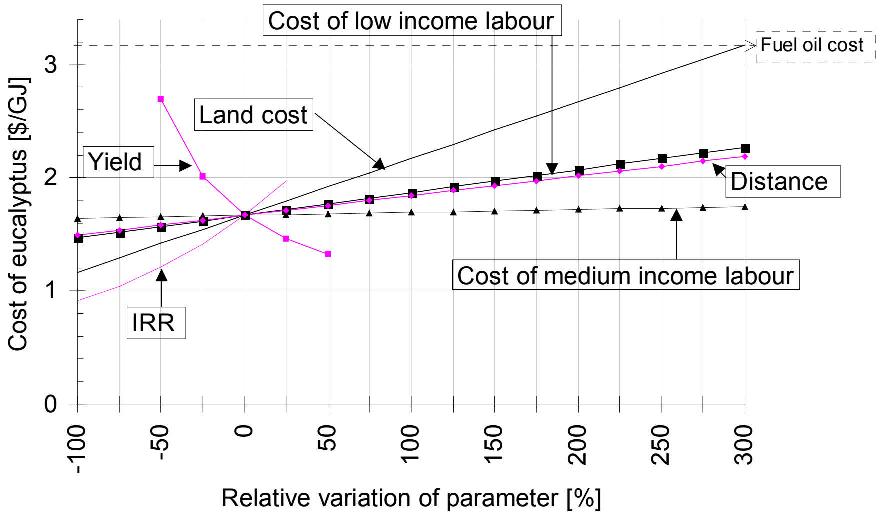

Figure 2. *Sensitivity of the cost of eucalyptus production for the most important assumptions in the cost calculation.*

4.2. Estimated cost of conversion into liquid fuel and transport to the Netherlands

In order to give an illustration of the meaning of the local cost of eucalyptus production for energy use in the Netherlands, we briefly compare two ways of converting it into liquid fuels. As an example, we choose the production of Fischer Tropsch liquids, since this turned out to be a relatively promising biofuel for the short term [12, 13]. We consider two possible routes: (i) transport of eucalyptus logs to the Netherlands for large scale conversion into FT hydro-carbons, (ii) local medium scale conversion of eucalyptus into FT hydro-carbons in Nicaragua and transport of the liquid fuel to the Netherlands. The rationale of choosing a larger scale plant in the Netherlands is that the wood supply in this case may come from various countries, whereas with conversion in Nicaragua this is assumed to be limited to locally supplied wood.

In this simplified assessment we use the assumptions as mentioned in Table 4.

It has to be stressed that wide ranges are found especially for costs of ocean transport of wood. The figure used is believed to be relatively conservative. The specific investment cost is about 40% higher in Nicaragua, because of the lower scale assumed. A very important assumption is the large difference in IRR used in Nicaragua and the Netherlands.

This is mainly caused by the higher investment risk in Nicaragua (see Table 1) and is based on actual practice in both countries.

The resulting costs per GJ of fuel produced (see Figure 3) does not differ significantly between the two alternatives, considering the uncertainties in the underlying assumptions. In the case of conversion in the Netherlands, the largest cost component is the fuel (in total about 60% of the total cost of the produced liquid fuel), whereas investment costs per GJ of liquid fuel produced is more than twice as high in Nicaragua, as a result of the smaller scale and the high minimum required IRR. The absolute value of the costs as calculated here should not be interpreted as representative for the lowest cost production of liquid biofuels. Transport over less distance, alternative conversion routes, optimisation of ocean transport (e.g. regarding return cargo and ship size) and of loading and unloading logistics may decrease costs in the longer term.

Table 4. Main assumptions made in the cost estimation of biotrade for liquid FT fuel production between Nicaragua and the Netherlands [12, 26, 27].

	Dimension	Conversion in Nicaragua	Conversion in the Netherlands
Scale considered (fuel input)	MW_{th}	400	1000
Efficiency (HHV)	%	43	45[a]
Investment cost	M$	287	544
Operation and maintenance	$\%_{\text{of investment}}$	4	4
Shipment cost of wood (incl. loading and unloading)	$\$/GJ_{\text{wood, LHV}}$	-	3.8[b]
Shipment cost of liquid fuel.	$\$/GJ_{\text{liquid}}$	1.2[c]	-
Load factor plant	%	80	80
Internal rate of return required	%	20	10

[a]In the original study[12] co-production of electricity and liquid FT fuel was assumed, with 40% efficiency on the fuel and an additional 10% for electricity. The 45% efficiency is considered as a reasonable estimate for a fuel only mode of such a plant.

[b]Lower estimates of about 2.5 $/GJ have been found for transport of wood from Uruguay to the Netherlands [28]. The 3.8 $/GJ value was believed to be more representative for transport from Nicaragua, since it was based on a case study on Ecuador, in which the ship was limited in size since it had to pass through the Panama canal. This would be the case in Nicaragua as well, because wood production would be likely to take place at the pacific side of the country. It has to be noted that both figures mentioned are relatively uncertain, since detailed experience lacks. Moreover, no return cargo was included in this estimate. This could reduce costs allocated to the transport of wood. Finally, about 45% of the costs consist of costs for loading and unloading [26]. Specific design of wood loading and unloading equipment may decrease these costs further.

[c]This figure is estimated from a cost figure of 0.26 $/GJ for transport of bio-diesel from a Baltic state to the Netherlands [13]. The distance is about 8 times as large and we assume that 50% of the cost is linear with the distance and that the rest is distance independent.

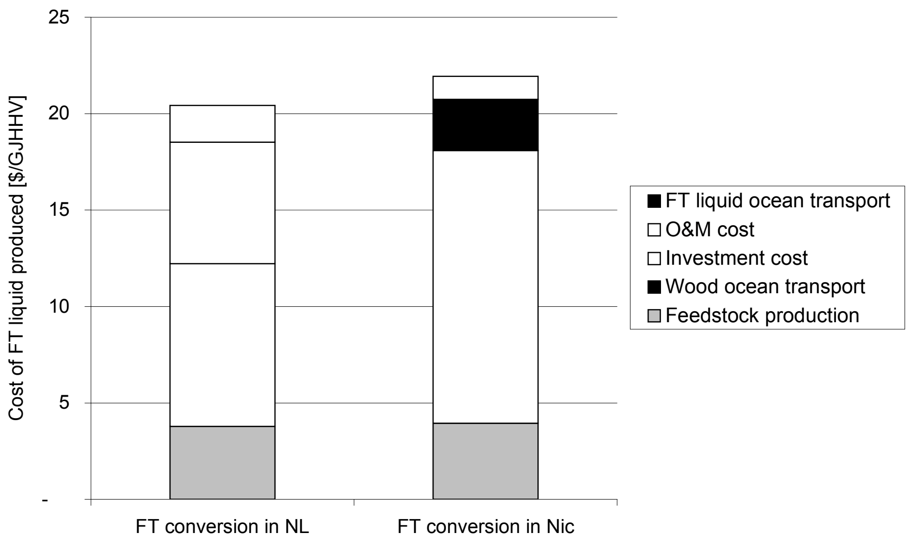

Figure 3. Estimated cost of the production of Fischer Tropsch hydro carbons from Nicaraguan eucalyptus for use in the Netherlands. The left bar assumes that the wood is transported as stems and converted into a large scale plant in the Netherlands, whereas the right bar assumes conversion in Nicaragua in a medium scale plant combined with ocean transport of the produced FT hydrocarbon.

5. Environmental impacts of eucalyptus cultivation in Nicaragua

Overall assessments of environmental impacts of biomass energy systems can basically only be undertaken when the whole chain including conversion is considered and compared with a system that it replaces. Since this is out of the scope of this study, the environmental analysis presented is for some environmental themes a partial analysis. This mainly accounts for impacts that potentially occur during conversion into liquid fuels and end use of these fuels, such as acidifying emissions. The reference land-use is the land use that would occur if there would have been no energy plantation. In previous work it was decided that shrub land is a suitable choice for this, since presently energy crops are not competing with agriculture. Generally this shrub land can be characterised as having an open vegetation with scattered low shrubs. Undergrowth is relatively abundant. The absence of an economic use, in practice leads to a lack of protection against fires, caused by field burning in agriculture. A precise characterisation is not possible, because the exact type of land cover of the locations where eucalyptus is planted may differ from site to site. If agricultural land would be replaced by energy crops in the future, an environmental assessment becomes more complex since it has to include induced land-use [5].

In Section 5.1 we first deal with the main emissions to air and fossil fuel use. In Section 5.2 up to 5.7, an (largely qualitative) overview is given of some local potential environmental impacts of eucalyptus cultivation as compared with the reference land use, being shrub land. As potential local impacts we include: erosion, loss of soil quality, groundwater eutrophication, emission of toxic substances, groundwater depletion, and loss of biodiversity.

5.1. Emissions to air and fossil energy use during eucalyptus production.

Figure 4 shows the main emissions that occur during the production of energy crops in Nicaragua. As a reference we included emissions and fossil fuel use of the production (exploration, exploitation, transport and refining) of fuel oil, a fuel that is widely used for electricity production in Nicaragua [3], and the production of willow in the Netherlands [29]. We included figures on the fossil fuel input and CO_2-eq. and SO_2-eq. emissions of transporting wood by an ocean vessel, to illustrate the order of magnitude of the environmental impact of wood transport from Nicaragua to the Netherlands [3, 26].

Figure 4 shows that, if locally used, fossil energy input for the production of eucalyptus is very low as compared to the production of fuel oil and the production of willow in the Netherlands. The latter difference can mainly be explained from the fact that at present no chemical fertiliser is used in the eucalyptus plantations and that the use of agricultural machinery is very low with eucalyptus cultivation since much work is done manually (e.g. manual weeding and harvesting with chain saws). A similar situation can be observed with the three types of emissions assessed, although differences regarding dust emissions are relatively small.

The situation changes when eucalyptus is imported as (untreated) wood to the Netherlands. In this case the fossil energy input is almost twice as high than that for willow cultivation in the Netherlands. If eucalyptus would be co-fired in a pulverised coal power plant in the Netherlands the energy output-input ratio would be about 8, whereas it would be about 35 if converted to electricity in Nicaragua [25].

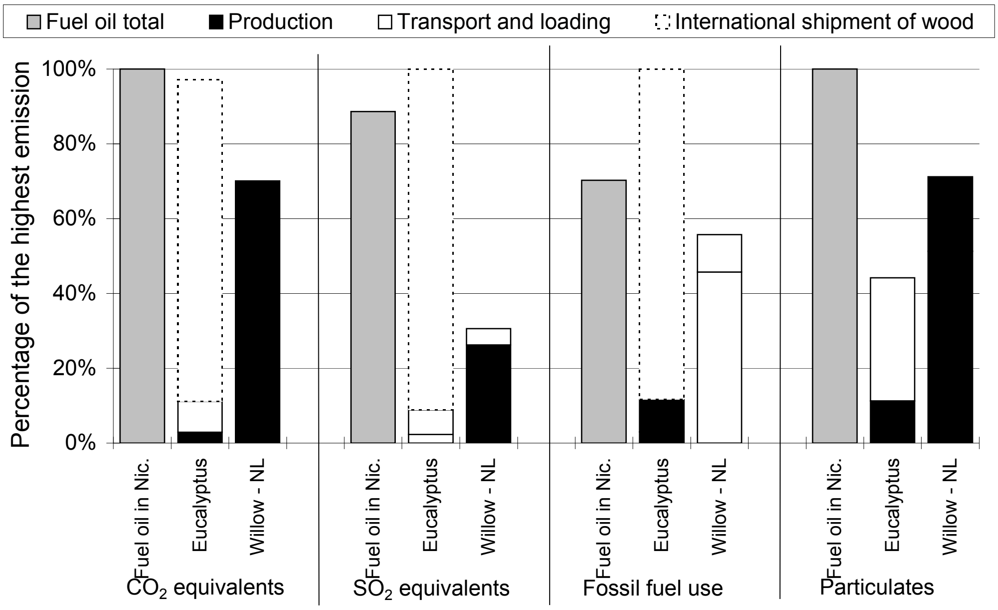

Figure 4. *Comparison of emissions caused by fuel production of (i) fuel oil imported to Nicaragua from Venezuela [3], eucalyptus production in Nicaragua [3], and (iii) willow production in the Netherlands [29]. Emissions are limited to the production and transport of the fuel; emissions during conversion of the fuel and during construction of the conversion facility are not included. The impacts are expressed as a percentage of the largest one. The 100% values are: CO_2-equivalents: 9 kg CO_2-eq./GJ, SO_2-equivalents: 0.2 kg SO_2-eq./GJ, fossil fuel use: 0.11 GJ_{fossil}/GJ and particulates: 5 g/GJ (for the latter no data were available for international shipment of wood).*

5.2. Impact on erosion

Wind and water erosion can lead to the loss of soil, the deterioration of the soil structure and to an increase of sediments going to surface water [30].

Eucalyptus plantations have the potential to reduce wind erosion by reducing the wind speed [30]. This is the explicit aim of a lot of linear small scale eucalyptus plantations in Nicaragua at this moment. Because of the higher length of eucalyptus trees than shrub land vegetation, wind erosion reduction is expected to be the highest with eucalyptus.

Trees can also play a role in preventing water erosion by the establishment of ground vegetation. Experiences with eucalyptus in this respect are relatively poor, because of its high tendency to suppress ground vegetation. However, *E. camaldulensis* at its turn performs better than other eucalyptus species as a result of its narrow crown and vertical orientation [30]. In an European study on environmental impacts of energy crops [31], eucalyptus scored the best of ten energy crops on water erosion prevention, mainly because it is an evergreen tree and therefore able to reduce the kinetic energy in raindrops during the whole year. Only during the first year after planting the plantation is relatively susceptible to erosion. Groundcover in shrub land will generally be more intensive than in eucalyptus plantations. The soil structure binding action of the tree roots is another water erosion preventing mechanism. Erosion tests in Brazil showed good erosion control with eucalyptus plantations, except for the first year of planting [32]. A sensitive point for erosion in forestry plantations in general are forest roads without a proper drainage system [32]. In areas susceptible to soil erosion it is advisable to minimise disturbance and to limit mechanical ground cover weeding. On slopes, contour ploughing is recommendable to minimise erosion [33].

5.3. Impact on soil quality

To assess the impact of eucalyptus plantations on soil quality, we focussed on the organic matter content and the nutrient status of the soil.

Experiences in several areas in the world have shown that afforestation with eucalyptus can improve soil fertility in the long term [32, 34]. This is especially the case with the organic matter content. The roots, leaves and unharvested branches add to the organic matter content of the soils. With the model results on the actual yield at San Antonio [35, 36], over 1.1 $tonne_{0\%}.ha^{-1}.yr^{-1}$ of carbon is added to the soil on average, by the leaves and not harvested branches.[1] In addition, carbon is added to the soil by the tree roots. Natural systems like shrub land have been found to add less carbon to the soil in Brazil [32]. However, representativeness for Nicaraguan circumstances of such complex processes is questionable. In Nicaragua shrub land with no economic use is more susceptible to fires, caused by field burning in agriculture, which leads to reduction of the amount of carbon that could have been added to the soil. Eucalyptus plantations are normally protected against fires.

In Nicaragua, at present, no fertilisers are applied in the eucalyptus plantations. Recent work [37] in Nicaragua attempted to quantify the total removal of nutrients from the site (Table 5). The results from this study have been converted with the model results on the actual yield at San Antonio. As a reference for the nutrient removal during the harvest, we show some figures of eucalyptus and sugarcane plantations. Except for calcium, the Nicaragua figures fall within the range for nutrient removal at eucalyptus plantations as mentioned in literature [32]. These losses will generally be higher than nutrient losses in shrub lands, where no harvests take place. Fires, resulting from the lack of fire control in shrub land, can cause significant nutrient losses too. With respect to the nutrient use efficiency, De Lima [32] showed higher values for eucalyptus than for pine trees, especially with respect to phosphorus.

Table 5. Indication of net annual deficit of nutrients at eucalyptus plantations in Nicaragua (all units in $kg.ha^{-1}.yr^{-1}$) [37] as compared to some results from literature on eucalyptus and sugarcane [32].

Nutrient	Input by deposition	Nutrient removal at harvest	Output by leaching[b]	Net annual deficit	Nutrient removal at harvest from literature [32]	
					Eucalyptus[a]	Sugarcane
N	0.6 - 2.3	19	5.3	22 - 24	29.5 (13.3-110)	208
P	n.a.[c]	6.5	n.a.	6.5	8.7 (0.9-11.2)	22
K	n.a.	24	n.a.	24	32.8 (11.7-94.9)	200
Ca	n.a.	200	n.a.	200	93.1 (13.2-95.4)	253
Mg	n.a.	8	n.a.	8	n.a. (4.8-13.1)	67

[a]The first value mentioned is for *E. camaldulensis* with a 9 year rotation; the values in brackets presents a range of other types of eucalyptus with various rotations.
[b]This should be considered as a rough indication, for it has been based on a regression equation in Africa: $L=2.3+(0.0021+0.0007*F)*R+0.3*N_f-0.3*U$, with L= leaching [$kg.ha^{-1}.yr^{-1}$], F= soil fertility class (1: low, 2: moderate, and 3: high), R= annual rainfall [mm], N_f= fertiliser applied [$kg.ha^{-1}.yr^{-1}$], U= total uptake by plant [$kg.ha^{-1}.yr^{-1}$] [38, 39].
[c] "n.a." means: no data available on this item.

Basically, large part of the minerals could be returned to the field by means of the ash that is produced in the power plant by burning the eucalyptus. A modest amount (compared to food crop fertilisation levels) of nitrogen fertilizer could restore the nitrogen balance. Apart from ashes and artificial fertilizers, residues from the sugar production process, which form a disposal problem at the moment, may be used [40]. Another alternative is inter-cropping of nitrogen fixing species, such as herbaceous legumes or nitrogen fixing trees [41, 42].

[1]Based on a yield of 13 $tonne_{0\%}.ha^{-1}.yr^{-1}$, a harvest index of 0.85 and a carbon content of eucalyptus of 48.5 $wt\%_{db}$.

5.4. Impact on groundwater eutrophication

Nitrogen leaching, as estimated by Hoogwijk [37] (see Table 4.1, note b), is likely to be comparable with nitrogen leaching of uncultivated shrub land, because neither of the two are fertilised. Limited fertilization may slightly increase leaching; fertilisation of 30 kg $N.ha^{-1}.yr^{-1}$ is estimated to increase leaching from 5 to 14 kg $N.ha^{-1}.yr^{-1}$. In general, it is not clear whether eutrophication is a problem in Nicaragua at the moment. The estimated range for nitrogen leaching in Nicaragua is, however, below the leaching level of 20-45 $kg_N.ha^{-1}.yr^{-1}$ (dependent on the amount of rainfall surplus) that is considered environmentally acceptable for grassland in the Netherlands, where eutrophication is a serious problem [43].

5.5. Emission of toxic substances

Soil organisms can be damaged by the use of pesticides and herbicides. Because eucalyptus is relatively free of pests and diseases, pesticide use can be very limited [11]. In Nicaragua it is only used against red ants at the planting of eucalyptus, and this only takes place in the first year of the plantation lifetime. At this moment no herbicides are used, although tests on its effectiveness are ongoing. In the future, the herbicide glyphosate may be used during the first years after planting when the plantation is still relatively vulnerable for weed [41].

As an indication, the available data on herbicide and pesticide were compared with the environmental impact points according to a Dutch classification system of pesticides and herbicides [5, 44]. Although the Dutch system may not be valid in Nicaraguan circumstances, it does give an indication of the toxicity of the pesticides and herbicides used [45]. It is based on European standards for pesticide and herbicide use. A score of 100 environmental impact points per hectare per impact parameter would be just within the European standard [46].

It was calculated that in the first year of the plantation (the establishment phase) the total score for the pesticides is 59 for water life, 9-31 for groundwater and 418 for soil-life. The first two are below the European standard of 100, but in the case of soil-life this standard is exceeded. In the other 23 years of the plantation lifetime, the score is zero on all three parameters.

5.6. Impact on groundwater level

Since neither eucalyptus nor shrub vegetation is expected to reach the groundwater level, direct extraction is assumed to be zero in both cases. The impact on the groundwater level therefore reveals itself in the impact on the replenishment of the groundwater. We concentrated on three factor that influence the replenishment of groundwater: (i) direct evaporation (interception) from the leaves, (ii) transpiration losses and (iii) evaporation from the soil.

The amount of rainfall that goes to the soil is limited by the direct evaporation of water that falls on the tree leafs and by the transpiration of the plant. Research in India noted a 23-28% decrease in water going to the groundwater (thus not intercepted by the crop) as compared to unforested land [30]. The direct evaporation from the leaves of eucalyptus is estimated between 10-25% of the total precipitation [30]. This is relatively low in comparison with natural forests or with other tree species, but higher than with shrub land like vegetation [30, 32, 34, 47-49].

Transpiration losses of water are inherent with primary production of plants. Specific for trees is that they can extract water during a long period, because of their deep rooting system. In most cases (like in the Nicaraguan one) the eucalyptus roots can not reach the ground water table and therefore the water consumption remains largely limited to the precipitation supply [32]. However, in case that the roots are able to reach the groundwater level, transpiration can exceed precipitation supply. An Australian example showed an annual transpiration of about 3600 mm with a precipitation of only 800 mm [48]. Eucalyptus is a relatively efficient water user, though. It uses less water per unit of biomass produced than most other trees and than most agricultural crops, but the total use can still be high because of its high production rate [32, 47, 50]. In areas where the water supply for other purposes is very critical, one should be careful with planting fast growing eucalyptus plantations. An alternative could be less intensive plantations (e.g. fewer trees per hectare).

Where annual rainfall ranges from 400 to 1200 mm, careful planning of the water balance is recommended before growing mixtures of agricultural crops and eucalyptus [49].

The influences of the land cover on evaporation from the soil mainly depends on the leaf area index. A higher leaf area index leads to lower soil evaporation. The leaf area index of eucalyptus, as a highly productive crop, is likely to be higher than that of shrub land. Therefore, evaporation from the soil is expected to be lower with eucalyptus plantations than with shrub land.

In order to give an impression of the shares of the various water losses we quantified the losses for an average rainfall year at San Antonio by using the results of the SILVA crop growth model [2]. For this purpose we used the crop growth model that was presented in Chapter 2. The model calculation showed that of the 1909 $mm.yr^{-1}$ of rain, 689 $mm.yr^{-1}$ is transpired by the eucalyptus, 107 $mm.yr^{-1}$ evaporates from the soil, 130 evaporates after leaf interception and 983 $mm.yr^{-1}$ mm drains into the soil from where it can replenish the groundwater. Whether in Nicaragua there will be a significant effect on the groundwater level, which may cause problems elsewhere, remains to be investigated in more detail on the specific location considered.

5.7. Impact on biodiversity

Generally, eucalyptus is known for its relatively poor wildlife value as compared to other types of trees. This is mainly caused by its small hard fruit and very tiny seeds, which are poor food for birds and by its leafs being unpalatable to deer. The relatively low amount of ground vegetation constrains plant and insect biodiversity. However, many eucalypts are attractive for bees, while their habit of dropping down stringy bark provides nesting material [30]. No data are available on the difference in biodiversity between eucalyptus plantations and shrub lands. At a 5 day-expert consultation of the FAO in 1993 [33], however, it has been stated in the overall conclusions that eucalyptus plantations have more divers fauna and flora than many types of degraded land.

Mixed plantations are mentioned by various authors as a means to increase habitats for wildlife [51, 52]. Another strategy is to maintain habitats for biodiversity within the plantations, such as open spaces, parts of natural vegetation, and corridors between these parts [32, 52]. At the moment maintaining such habitats is already common practice within the San Antonio plantations [41].

6. Socio-economic impacts of eucalyptus cultivation in Nicaragua

Regarding socio-economic impacts we focus on the impact of the cultivation of eucalyptus on the Gross Domestic Product (GDP) of Nicaragua, on the amount of local employment that is generated from producing eucalyptus and on the distribution of the income among the various income groups (low, high and medium income groups in society. A positive score on these impacts would contribute to improve three socio-economic problems of Nicaragua as shown in Table 1, i.e. the small GDP per capita, the negative trade balance, the high unemployment, and the high inequality of income. We distinguish between two types of eucalyptus production: the first is industrial production of eucalyptus by a large company (e.g. a sugar mill) and the second is eucalyptus production by small scale farmers on their own land. Both types of eucalyptus production already exist in Nicaragua. About 10,000 ha of industrial eucalyptus plantations have already been planted in the last decade in Nicaragua.

During the same period, under the (FAO/DGIS based) regional development project "Los Maribios", another 3,000 ha of wood plantations (mainly eucalyptus) have been planted in small lots by individual farmers, partly in agroforestry systems [8]. Previous work [4] has also shown that basically it is feasible that these farmers do not only supply the existing urban wood fuel market, as is the case at the moment, but also supply the bagasse / eucalyptus based electricity plant of the largest sugar mill of the country. The Los Maribios association has already shown interest in selling (part of) their wood to the international pulp and paper market. Interest from Japan has already been shown, in this respect, for wood from both the plantations of the sugar mill and the farmer association.

Figure 5 shows where the money that is spent on producing eucalyptus ends up. Basically looking from the Nicaraguan economy, ultimately this money can be either value added for the economy, thus contributing to the Gross Domestic Product of the country, or go abroad as payment for exports. We used input-output analyses in order to calculate indirect effects [3]. As a reference, again, we use the production of fuel oil in the refinery in Managua, the capital of Nicaragua.

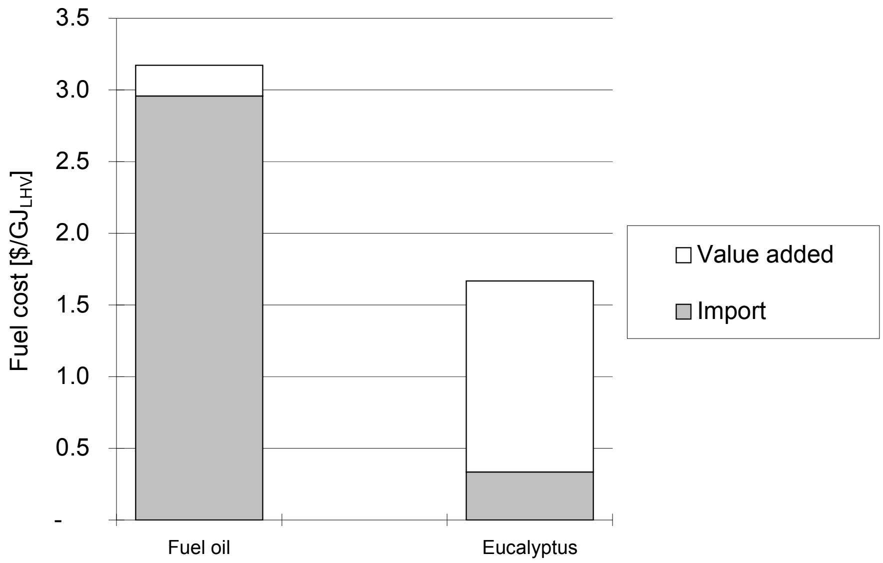

Figure 5. *Distribution of the money spent on the production of fuel oil and eucalyptus over import and value added to the economy of Nicaragua [3].*

Figure 5 shows that when fuel oil is produced, about 93% of the total expenditures flows out of Nicaragua, mainly to pay for the import of crude oil. The contribution to the Nicaraguan economy is minimal. In the case of eucalyptus production, however, only 20% of the money spent (0.3 $/GJ) is needed to pay for importation of goods that are directly or indirectly needed to produce eucalyptus.

The rest, 80% (or 1.3 $/GJ) ends up as value added, thus adding to the national GDP. If eucalyptus replaces fuel oil in Nicaragua, this would lead to a decrease of imports and consequently to an improvement in the presently negative balance of payment (see Table 1). When eucalyptus would be produced for exportation, a small amount of additional import would be needed, but this would be less than 20% of the export earnings from selling the wood , assuming that the price paid for the wood would at least be 1.7 $/GJ (cost price of wood including profit).

Figure 6 compares farm-based and industrial plantations by presenting the cost break down and the distribution of income of the two plantation types. The higher land costs of the industrial plantations (left-hand side of Figure 6) are caused by the higher discount rate the sugar mill uses. In the farm-based plantation, the production costs are higher than in the industrial one because of higher establishment and management costs.

Furthermore, costs for logistics (transport and (un)-loading) are higher since additional in-field transport is assumed to be necessary in all cases. The largest difference between the two is the profit that goes to the farmer instead of to the sugar mill. This profit is the money the farmer earns on top of a compensation for his labour (assumed to be equal to the minimum wage of Table 3) and a 47 $\$.ha^{-1}.yr^{-1}$ compensation for land use.

The right-hand side of Figure 6 shows the amount of import needed and the total amount of national income (value added) that is generated. Creation of national income is slightly higher in the farm-based eucalyptus case (83 instead of 80%). Import is somewhat higher in industrial plantations as a result of more machine and diesel use. Low income groups have the most direct benefit from the farm-based option, where 77% of the value added created goes to small scale farmers as compensation for both labour and land. In the case of industrial plantations this is between 17 and 47%, depending on who owns the land. In industrial plantations, a large part, about 44%, of the value added is profit for enterprises, mainly the sugar mill itself.

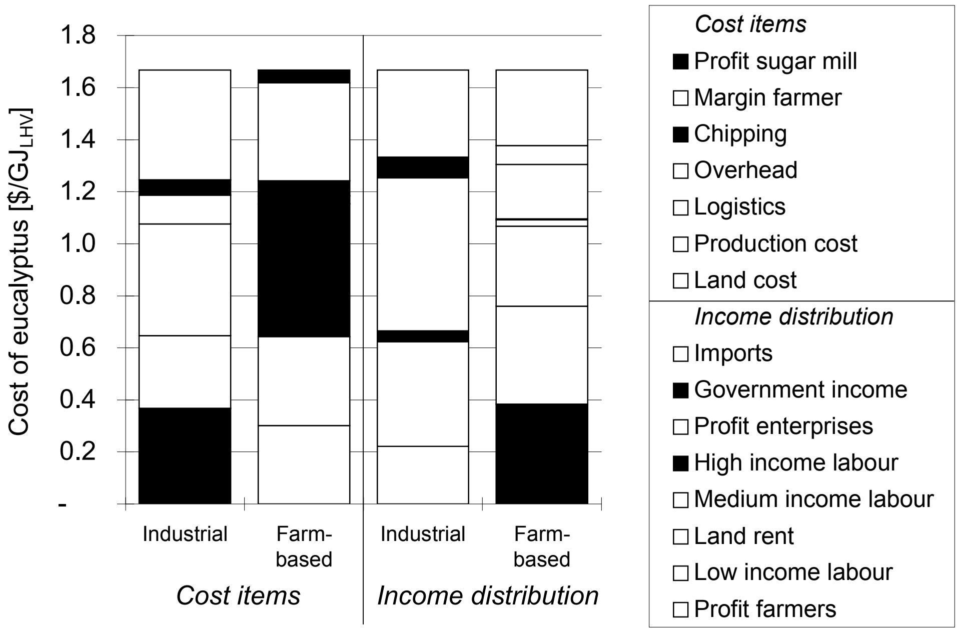

Figure 6. *Break down of the production cost of eucalyptus (left-hand side) and the distribution of income generated by this product (right-hand side) [4]. Both are given for industrial and farm-based production of eucalyptus. In the latter case, we assume that the sugar mill buys the wood as standing stock and pays its avoided cost.*

With respect to the employment creation, we included both directly and indirectly generated employment. It was found that farm-based eucalyptus production generates over two times more employment than the industrial option (250 against 575 man.yr/$PJ_{fuel,LHV}$).

The largest part of employment in both cases is low cost labour (about 90% of the jobs created in both cases). The option of industrial wood plantations still generates over a factor 6 more jobs in Nicaragua per PJ of fuel than the production of fuel oil in the refinery of Managua.

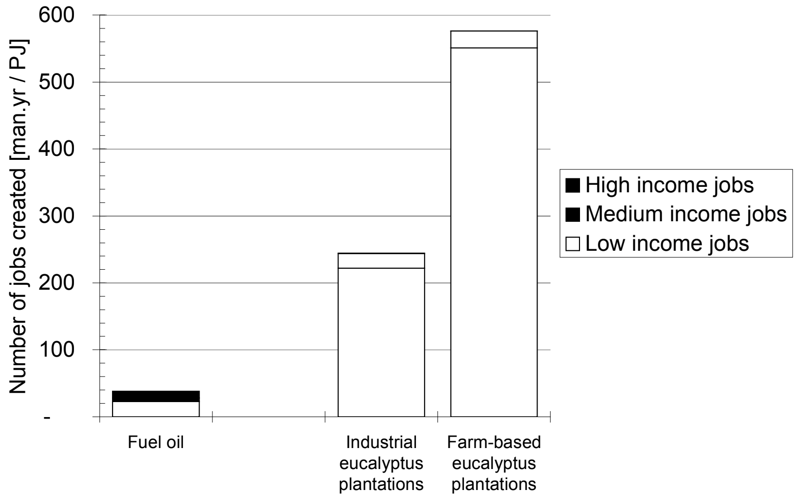

Figure 7. Employment generation by the production of fuel oil in the refinery of Managua versus two types of producing eucalyptus, i.e. industrial plantations and farm-based plantations.

7. Safety and reliability of energy crop production

Safety considerations do not play a very crucial role in the cultivation of a short rotation forestry crops such as eucalyptus. The only potential danger occurs during the harvesting process, since this is done manually by chain saws. When normal safety procedures are followed there is no reason to assume that unacceptable risks regarding safety are present here.

The reliability of the supply can be affected by many factors, like the risk of fire, the risk of unfavourable growing conditions (e.g. drought), risk of pests or diseases, and the risk of natural disasters destroying existing plantations. Fire risk is always present in large scale woody plantations. In Nicaragua, many farmers clean their agricultural fields by burning practices. This serves as a potential fire risk for surrounding trees, especially under dry conditions. Several measures can be and are presently undertaken to reduce this risk to a minimum, including clearing a stroke of land surrounding the plantation to prevent fires from outside to enter the plantation, limiting high undergrowth and removing dead dry wood, as a possible source of fire within the plantations. It already appeared in several cases in Nicaragua, that modest fires within the plantations sometimes only destroys undergrowth and dead leaves on the soil, but does hardly affect the trees. The risk of unfavourable growing conditions is always present in agricultural activities. A advantage of short rotations energy crops (the rotation of eucalyptus is about 6 years) that the occurrence of such drought is normally levelled out in the production, since harvests only take place after a couple of years. At present, there have hardly been any pests and diseases in the eucalyptus plantations in Nicaragua, except for ants that try to eat the eucalyptus plants just after planting (and for which pesticides are used). However, the scale of the plantations is still relatively small. Large scale (e.g. 100,000 ha) of eucalyptus plantations close to each other may increase such risks. A good way to limit this risk is to plant more tree species than only Eucalyptus camaldulensis. Nicaragua is situated in an area that is relatively susceptible to hurricanes, volcanoes and earthquakes. Especially hurricanes can be a thread to young plantations. During the recent hurricane Mitch, which destroyed almost the complete harvest of Nicaragua, most eucalyptus plantations survived. However, there were about 100 hectares of eucalyptus plantations lost as a result of a collapsing volcano wall near the San Antonio sugar mill.

8. Illustration of the possible large scale import of wood from Nicaragua

In this section we illustrate what the production of 20 PJ of biomass as an export product (either before or after conversion into a liquid fuel) would mean for a country like Nicaragua.[2]

Table 3 showed that the yield that was expected at the eucalyptus plantations of the San Antonio sugar mill in Nicaragua is about 13 $tonne_{db}.ha^{-1}.yr^{-1}$. At the eucalyptus of another sugar mill, Victoria de Julio, yield were close to 10 $tonne_{db}.ha^{-1}.yr^{-1}$ on average. This lower yield can mainly be explained from the fact that this is one of the dryest areas of Nicaragua. When larger areas are to be planted with energy crops probably less suitable soils may have to be used as well. Therefore, in this analysis we assume that the average yield to be expected at a large scale will be the present yield at the Victoria de Julio sugar mill.

This yield of 10 $tonne_{db}.ha^{-1}.yr^{-1}$ ....

- means that per hectare about 175 GJ of biomass is produced, which is
  - enough to produce about 2500 litres of FT diesel
- could produce fuel for about 2 kW_e of baseload electric capacity in Nicaragua

20 PJ of energy crop production for export per year.....

- requires a land area of about 110,000 ha, which is about:
  - equal to 1 thousand km2 of land
  - equivalent to the area of a square of 33 by 33 km
  - 1% of the total land area of Nicaragua
  - 5% of the total arable land area of Nicaragua

- equals about 10% of the total primary energy use of Nicaragua
- could also be used to fuel an electric base load capacity of about 66% of the total installed 1997 electric capacity of Nicaragua

- requires about 325 truck deliveries per effective working day to the harbour when the wood is directly transported; which:
  - means about 20 trucks per effective working hour
  - means about 1 truck per three minutes
  - is about half the amount of truck that deliver sugarcane to the San Antonio sugar mill in Nicaragua during an average day in the sugarcane season
- requires about 1 ship load of wood per 2 days

- means gross export earning (if sold as wood for a price that equals the total cost) of about 33 M$ per year, which is:
  - about 4% of total export earnings of Nicaragua in 1998

- means gross export earning (if sold as FT diesel for the a price that equals the total cost) of about 178 M$ per year, which is:
  - about 23% of total export earnings of Nicaragua in 1998
  - about equal to the total present annual expenditure for oil related imports in Nicaragua

- means a total employment creation of about 5000 person.year in the case of industrial plantations or 11000 person.year in the case of farm-based plantations, which is:
  - about 2-4% of the presently unemployed labour force of Nicaragua.

[2] The amount of 20 PJ is according to the terms of reference of the GRAIN project. This is about 17% of the total target which the Dutch government has for the contribution of biomass and waste in the year 2020.

- means an estimated total contribution, if the biomass would be sold as wood (for a price that equals the total cost), to the national GDP of about 26 M$ per year, which:
  - at itself would increase the GDP of Nicaragua with about 1% .

9. Discussion and conclusions

- The cost level of energy crop production in Nicaragua at present is about 1.7 $/GJ. This is just below the cost level of previous assessments of costs for wood production by ADL.
- Overall environmental impacts of eucalyptus production are positive as compared with its fossil fuel alternative and the reference land-use, being shrub land. Some areas that need more detailed investigation at the specific location of planting are: nutrient status of the soil, water use and biodiversity. It can be recommended to make modest use of fertiliser (which is hardly the case at the moment) in order to prevent deterioration of the soil. Moreover, it is recommended not to plant in areas which are susceptible for changes in groundwater levels. Finally, in order to maintain a certain level of biodiversity, it is recommended to leave natural niches in their original state within a plantation and not to plant in areas of high natural value.
- Ocean transport of wood would significantly increase fossil energy use and related emissions in the biomass energy chain. However, resulting fossil energy use is comparable to the indirect energy use (e.g. for exploitation, transport and refining) of fuel oil as used in Nicaragua. The energy output-input ratio for electricity production in the Netherlands from wood cultivated in Nicaragua would still be about 8.
- Socio-economic impacts of eucalyptus cultivation are positive on all aspects (employment creation, value added generation, reduction of import). This is especially the case with farm-based eucalyptus plantations, where a larger share of the income generated ends up with low income groups.
- The amount of land needed for 20 PJ is 1% of the land area in Nicaragua, which should not be considered as insignificant. Further research is required to judge in detail how realistic it is to plant energy crops at such a land area in Nicaragua, against the background of a growing agricultural production. Between 1980 and 1997, agricultural land-use increased from about 10% to 20% of the total land area of Nicaragua.
- Although large scale logistics are required for the export of 20 PJ of wood from Nicaragua, such logistics are not uncommon. The largest sugar mill factory in Nicaragua requires the double amount of trucks per day for supplying sugarcane during the sugarcane season.
- An export of 20 PJ of wood is estimated to raise the total GDP of Nicaragua with 1% and to reduce the amount of unemployed people with 2-4%.
- When Nicaragua would produce about 20 PJ (primary energy) of FT hydro carbons for export purposes, this export would about equal its present import of oil products. It can be questioned how realistic this situation is in the long term.
- Additionality, which plays a role in the discussion regarding CDM projects, is a discussion point as well for import of wood. When the Netherlands would offer an attractive price for the existing eucalyptus plantations in Nicaragua, this wood can probably be bought immediately. However, this would lead to less electricity production from biomass in Nicaragua (which is the present purpose of the wood), so that the net effect on greenhouse gas emissions may be negligible. This can be avoided by assuring that wood comes from additionally planted trees.
- To safeguard that imported wood comes from sustainable managed plantations, some form of control may be needed. For the environmental dimension of sustainability, one could consider and/or learn from certificates like the existing FSC (Forest Stewardship Council) certificate, with its related control system. Regarding socio-economic aspects, “Fair-Trade-like” certificates could give an additional value added to the sustainable character of the energy produced.

- An illustrative estimation was made of the cost of producing FT hydro-carbons from energy crops from Nicaragua. It was found that, with the data used in this study, there was no significant difference in transporting wood or hydro-carbons from a cost point of view, considering a possibly lower factory scale in Nicaragua, combined with a higher investment risk. This calculation should be considered indicative only.
  On the one hand FT hydro-carbons may not be the cheapest solution in the long term. Investigating this is however, out of the scope of this study. Moreover, there are still much uncertainties regarding the cost of ocean transport of wood. The figure used is a quote for the short term, assuming a relatively small ship and no return cargo. It is expected that optimisation of these logistics could still lead to cost reductions. More research in this respect is needed.
- The parameters used in the cost calculation have a dynamic character. Future developments may e.g. increase labour wages in Nicaragua, but may also decrease investment risks and therewith decrease the minimum required internal rate of return on investments.
- The assessment of socio-economic and environmental impacts was based on shrub land as a reference system. When high prices would be paid in the future for large scale wood production for export, it is well possible that competition with agricultural land will occur. This would change both the environmental and the socio-economic reference system. The result of this change depends of the type of agricultural system that is replaced. Regarding socio-economic consequences this means that a system is replaced that already supplied some level of employment and value added. The foregone agricultural production needs to be imported after the replacement by wood production (for an example of such a comparison, see Vlasblom and Van den Broek [25, 53, 54]). Regarding environmental impacts the situation is more complex, since the system borders do not stop at the country frontier here. When less agricultural product is produced in Nicaragua, this may lead (with an unchanged food demand) to additional food production elsewhere with related environmental impacts. This is called the induced land use [55], which basically has to be included in the environmental comparison. Attempts to deal with this complex problem have been presented by Van den Broek [29] and Junk [56].

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