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The Water Footprint of Bioenergy

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Summary

Fresh water is an important natural resource which is limited and scarce. Fossil energy is another important resource which is associated with emissions of greenhouse gasses. An alternative energy source is bioenergy, such as biomass from crops, which consume fresh water to grow. Therefore, there is an interaction between fresh water and bioenergy. The objective of this research is to quantify the relation between fresh water and bioenergy. The research contains three sub-objectives, the first is to assess the volume of water which associates with one unit of bioenergy produced in the current system. The second is to assess this for an optimal system where biomass and bioenergy are produced more efficient. The third sub-objective is to assess the volume of water which associates with the current consumption of bioenergy.

Basis for the calculation of the relationship between water and bioenergy is the water footprint concept. The research includes input from three systems: the energy, the agriculture, and the water system. The first regards the kind of energy and the amount of energy which can be obtained from biomass. Here primary energy is the energy of the whole plant, secondary energy is energy or energy carriers made from this biomass. The current system regards secondary energy as biodiesel, ethanol, or power which are produced with 'conventional processes'. Part of the optimal system, second transformation, includes second generation processes to also utilize crop residues. Second is the agriculture system, this regards biomass yields and cultivation characteristics. The current system regards current yields and current cultivation characteristics. The second part of the optimal system, HEI-system, uses different cultivation characteristics, such as irrigation, to achieve higher yields. The water system regards water consumption during crop cultivation. This consists of soil moisture (green water), irrigation water (blue water), and pollution caused by fertilizers (grey water).

The average water consumption of bioenergy in the current system varies greatly per crop and per kind of energy (-carrier). The average water consumption of primary energy in the current system ranges from 20 to 80 $m^3/GJ\ HHV$. The average of secondary energy ranges from 40 $m^3/GJ\ HHV$ for ethanol from sugarbeet to 500 $m^3/GJ\ HHV$ for power from rape (oil). The optimal system consists of second transformation and the HEI-system. Both components of the optimal system can be combined. In this case, the average water consumption of liquid biofuels (biodiesel and ethanol) ranges from 20 to 40 $m^3/GJ\ HHV$. The total water footprint of bioenergy consumption, as covered in this research is 1500 Gm^3/yr. Compared to the global water consumption this is a considerable amount. Therefore, consumption of bioenergy has a large impact on fresh water resources.

Samenvatting

Zoetwater is een belangrijke, maar ook schaarse hulpbron. Fossiele energie is eveneens een belangrijke hulpbron, maar wordt geassocieerd met de emissie van broeikasgassen. Een alternatieve energiebron is bio-energie, zoals biomassa van planten die zoetwater gebruiken tijdens de groei. Er is dus een relatie tussen zoetwater en bio-energie. Het doel van dit onderzoek is het bepalen van deze relatie. Dit bestaat uit drie andere doelen: de eerste is het bepalen van het volume water dat nodig is om bio-energie to produceren in het huidige systeem. De tweede is het bepalen van het volume water dat nodig is om bio-energie to produceren in een optimaal systeem. Het derde doel is het bepalen van het volume water dat hoort bij de huidige bio-energy consumptie.

Grondslag voor de berekening van de relatie tussen water en bio-energie is het water footprint concept. Hiervoor gebruikt dit onderzoek informatie uit drie systemen: het energie-, het landbouw- en het watersysteem. In het eerste systeem wordt bepaald welke vorm van energie en hoeveel energie wordt geproduceerd uit biomassa. Hier is primaire energie de energiewaarde van de hele plant, secundaire energie zijn producten die zijn gemaakt van de plant. Het huidige systeem richt zich op secundaire energie zoals: biodiesel, ethanol en elektriciteit, deze worden geproduceerd met huidige processen. Het eerste deel van het optimale systeem, ‘second transformation’, bevat tweede generatie processen waardoor ook plant restanten gebruikt worden. Het tweede systeem is het landbouwsysteem. Dit betreft gewas opbrengsten en landbouw karakteristieken. Het huidige systeem richt zich op huidige opbrengsten en huidige landbouw karakteristieken. Het tweede gedeelte van het optimale systeem, ‘HEI-system’, heeft andere landbouw karakteristieken, zoals kunstmest of irrigatie, waardoor hogere opbrengsten worden behaald. Het watersysteem richt zich op de water consumptie van planten. Dit bestaat uit regenwater (groenwater), irrigatie water (blauwwater) en vervuiling van water door kunstmest gebruik (grijswater).

Het gemiddeld watergebruik van bio-energie varieert in grote mate tussen verschillende planten en energievormen. Het gemiddeld watergebruik van primaire energie in het huidige systeem ligt tussen de 20 en 80 $m^3/GJ\ HHV$. Het gemiddelde van secundaire energie loopt uiteen van 40 $m^3/GJ\ HHV$ voor ethanol uit suikerbieten tot 500 $m^3/GJ\ HHV$ voor elektriciteit uit koolzaad (olie). Het optimale systeem bevat ‘second transformation’ en ‘HEI-system’, deze twee onderdelen kunnen worden gecombineerd. In dit geval ligt de gemiddelde waterconsumptie van vloeibare biobrandstoffen (biodiesel en ethanol) tussen de 20 en 40 $m^3/GJ\ HHV$. Het volume dat hoort bij de huidige bio-energie consumptie is 1500 Gm^3/yr. In vergelijking tot andere bronnen van watergebruik is een grote hoeveelheid. Daarom heeft de consumptie van bio-energie grote invloed op het gebruik van zoetwater.

Voorwoord

Dit rapport markeert het eindpunt van mijn studie civiele techniek. Voor een afstudeeropdracht was ik op zoek naar iets breeds en nieuws, dit is toen de water footprint van bio-energie geworden. In het begin was de kennis van dit onderwerp dan ook gelimiteerd tot algemene begrippen als waterschaarste en biodiesel en dat de relatie tussen deze twee ligt in de landbouw sector. Echt grip krijgen op het systeem van dit onderzoek kostte dan ook de nodige tijd. Terwijl het systeem van het onderzoek duidelijker werd, werd het onderzoek zelf ook groter en breder. In het begin was het doel van het onderzoek beperkt tot de water footprint van primaire energie, nu bevat het ook secundaire energie met een optimaal system.

Tijdens het onderzoek heb ik steun gehad van vele mensen en deze wil ik hiervoor dan ook bedanken. Als eerste(n) zijn dit mijn drie begeleiders die ik wil bedanken voor het leveren van commentaar op alle verslagen, meestal op korte termijn, en voor het beantwoorden van vragen, zelfs wanneer deze nogal vaag waren. Extra dank gaat uit naar mijn dagelijks begeleider Winnie, voor je snelle commentaar en kritische blik op de tekst van de eerste tot en met de laatste versie van het rapport. Verder gaat dank uit naar mijn ouders, huisgenoten voor support, het aanhoren van alle proef presentaties. Ten slotte wil ik nog de mede afstudeerders en WEM collega's bedanken voor de werksfeer, maar ook de introductie tot Latex. Het programma dat, na veel gepruts, verantwoordelijk is voor het uiterlijk van dit verslag.

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Chapter 1

Introduction

1.1 Introduction

Freshwater is an essential natural resource for basic human needs such as food, drinking water and a healthy environment. In the coming decades, humanity will face important challenges, not only to meet these basic human needs but also to ensure that the extraction of water from rivers, streams, lakes and aquifers does not affect freshwater ecosystems to perform their ecological functions [Gerbens-Leenes et al., 2008]. Humanity already uses 26% of the total terrestrial evapotranspiration and 54% of accessible runoff [Postel et al., 1996]. There are reasons for profound concern in several regions and countries with limited water resources if food needs of future generations can be met [Fischer et al., 2000] [Postel, 2000] [Rockstrom et al., 2007] [Vorosmarty et al., 2000].

It is generally accepted that emissions of greenhouse gasses, such as CO_2 from fossil energy, are responsible for anthropogenic impacts on the climate system. A shift towards CO_2-neutral energy, such as bioenergy, is heavily promoted. Other advantages of this renewable energy source are a decreased risk of energy supply insecurity, resource diversification, and the absence of depletion risks [UNDP, 1997] [Gerbens-Leenes et al., 2008]. Typical sources of bioenergy are: trees, but also food crops such as: maize, sugarcane, and rapeseed, which provides the basis for ethanol and biodiesel.

Crop production in the agriculture sector corresponds with about 90% of the global freshwater consumption [Hoekstra and Chapagain, 2007]. In many parts of the world, the use of water for agriculture competes with other uses such as urban supply and industrial activities [Falkenmark, 1989], while the aquatic environment shows signs of degradation and decline [Postel et al., 1996]. A shift from fossil energy towards bioenergy requires more crops to be produced in the agriculture sector, which further stresses freshwater resources.

An example of the interaction between bioenergy and stress on the freshwater resources is the Ogallala aquifer. The Ogallala Aquifer covers approximately 20.000 km^2 and is a major source of water in the United States. The water of the aquifer is used faster than it is being replenished, and the result is predicted by many to be serious eco-centric pressure on the area in the not so distant future [Guru and Horne, 2000]. Water withdrawals are used for irrigation of crops such as maize [Nadal and Wise, 2004]. Currently 15% of the maize area is irrigated [Nadal and Wise, 2004], the same amount of maize (13%) is used for the production of bioenergy (ethanol) [Patzek, 2006]. A stop of the production of this bioenergy, makes therefore irrigation of maize unnecessary. Which would therefore cease to stress the already water mined Ogallala aquifer. This example covers interaction between bioenergy and water. However, it claims a total stop of cultivation is required, because it only focuses on irrigation water. A broader analysis of the interaction between fresh water and bioenergy requires a different concept.

A concept which measures the interaction between fresh water and products is the water footprint concept. This was introduced by Hoekstra and Hung in 2002 and was developed to have an indicator of water use in relation to consumption of people. The water footprint concept includes the virtual water concept. Virtual water is the amount of water required to produce one commodity or service, where the water footprint is the amount of water required to produce the commodities and services consumed. The water footprint concept distinguishes three kinds of water consumption: soil moisture (green water), surface and ground water (blue water), and pollution of water (grey water). It then distributes the consumed volume of water over the various valuable products that are produced with this water [Hoekstra and Chapagain, 2007] [Chapagain et al., 2006]. This study uses this concept and applies it to the interaction between fresh water and bioenergy.

Several studies have already investigated the volume of water required to produce one unit of bioenergy. Gerbens-Leenes et al. [2008] have used the water footprint concept to assess the relation between the energy content of the whole crop for a large set of crops in different countries. However, that study excludes differentiation between the three kinds of water. Berndes [2002] has used a different method to assess this relation for energy content derived energy carriers and included also modern technologies. However, the different method allows no differentiation between the three kinds of water. Further did it not include the use of residues, with for example second generation technologies. Another study was done by Fraiture et al. [2007] and measured the marginal cost of water consumption for bioenergy production with the WaterSim model. This contains a differentiation between blue and green water. However, the focus of the study was not the interaction between fresh water and bioenergy, but the spacial (water) impact of an increased demand. Therefore, it lacks differentiation between various kinds of bioenergy.

Current researches cover a broad range of topics. However, many research aspects re still not covered. These are for example: differences among kinds of water consumption, among sources of bioenergy, among various types of bioenergy, among different spatial scales, and between the current situation and a future optimal situation. This study uses a broader setup and fills these blank spots.

1.2 Research objective and scope

The research objective is to *quantify the interaction between fresh water and bioenergy.* For this it uses the water footprint concept. This general objective consists of three more detailed objectives with their sub-objectives.

- To assess the volume of water which associates with one unit of bioenergy produced in the current system.
  - Assess differences among various sources for bioenergy, kinds of bioenergy, consumption of three kinds of water, differences between a global scale and national/local scale, and options of water savings due to the use of different sources for bioenergy.
- To assess the volume of water which associates with the current consumption of bioenergy.
  - Assess the impact on water consumption of bioenergy compared to other sources of water consumption, differences among kinds of bioenergy, and the water consumption of large scale shift from fossil energy towards bioenergy consumption.
- To assess the volume of water which associates with one unit of bioenergy produced in an optimal system.
  - Assess the lower limit of water which associates with one unit bioenergy, the water savings of the optimal system, and the differences between the current and optimal system.

This research includes and limits itself to the following subjects. Energy concerns gross produced energy and includes primary and secondary bioenergy. The latter contains first and second generation bioenergy. Consumption of bioenergy regards the year 2005. Agriculture includes food and non-food crops. Crop production regards national averages of 50 countries. Crop production occurs either in a countries current system, or in a High External Input (HEI) production system. Water includes direct green, blue, and grey water consumption in the agriculture sector. Here grey water consumption is based on pollution caused by the application of nitrogen in in-organic fertilizers.

Chapter 2

System description

2.1 Introduction

This chapter describes the system of biomass for bioenergy. This system is part of three other systems: the energy system, the agriculture system, and the water system. The next three sections present these systems. A fourth section describes the part where the three systems overlap.

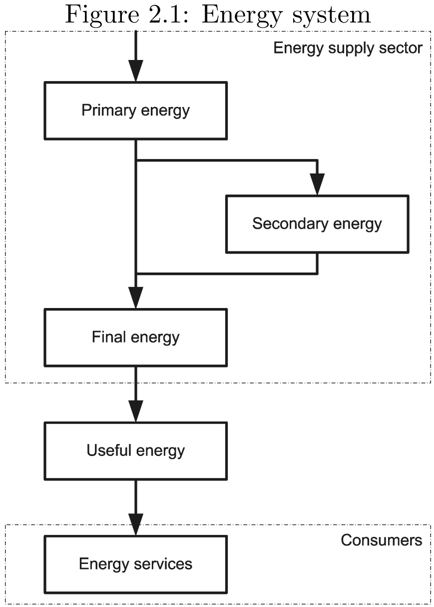
2.2 Energy system

The energy system consists of a supply sector and end-use technologies [UNDP, 2000]. The energy supply sector delivers energy to the consumers. The end-use technologies convert this delivered energy into benefits for consumers. In 2005 the major source of energy of the supply sector was fossil energy, which supplied 81% of the energy [IEA, 2008]. Non-fossil sources make up for the rest of the energy, these are nuclear energy (6%) and renewable energy (13%). Examples of renewable energy and their share in the total energy supply are: bioenergy (10%), hydropower (2%), wind energy ($0,1\%$), and photo voltaic ($< 0,01\%$) [IEA, 2008].

Bioenergy is defined as energy from biofuels. *Biofuels* are defined as fuels produced directly and indirectly from biomass. *Biomass* is defined as all material of biological origin, excluding material embedded in geological formations and transformed to fossil [FAO, 2006b].

Strictly spoken energy in energy statistics refers only to heat or power [IEA, 2005], however energy statistics commonly also include fuels. Together these are called energy commodities or energy carriers. Fuels are defined as energy carriers that are combusted to obtain energy [IEA, 2005]. Figure 2.1 shows the general shape of an energy system. Here *primary energy* consists of energy carriers which are extracted directly from natural resources [IEA, 2005] [Blok, 2006]. *Secondary energy* consists of energy carriers which are produced from other energy carriers [IEA, 2005] [Blok, 2006]. Consumers receive a mixture of primary and secondary energy carriers, such as natural gas and electricity, termed final energy. An example of an energy system is a car which uses maize ethanol as fuel. It starts with a farm that grows maize, this maize is the primary energy carrier of this system. An ethanol-plant converts the maize into ethanol, which is a secondary energy carrier. Combustion of the ethanol gives the car acceleration, which is useful energy. The energy service is road travel or the reached destination.

Figure 2.1: Energy system



Modified from: [UNDP, 2000]

The conversion of secondary energy from primary energy splits into two groups: first generation and second generation conversion processes. First generation conversion processes include biochemical, oil extraction, and thermochemical processes. Biochemical and oil extraction use the 'food' part of 'food crops'. Thermochemical processes include combustion of biomass and (current) pyrolysis. Examples are the production of ethanol from sugar and starch, the production of biodiesel from oils, and the production of charcoal or power from biomass [Hazell and Pachauri, 2006].

First generation conversion processes contain inherent limitations. Examples are the attainable yield of sugars, starch, or oil [Hazell and Pachauri, 2006]. Other issues are the poor or negative energy balance of several fuels [Ivens et al., 1992] [Pimentel and Patzek, 2005].

Second generation conversion processes are not yet commercially available, but allow some limitations to be overcome. Second generation conversion processes contain two groups of processes: thermochemical processes and biochemical processes. The first group includes gasification and pyrolysis which involve a thermal breakdown of biomass at high temperatures to generate gaseous (syngas) or liquid (bio-oil) fuels. Biochemical processes rely on the enzymatic conversion of cellulose [Hazell and Pachauri, 2006] or hemi-cellulose [Reith et al., 2002] to sugar. These processes then convert this sugar into ethanol [Hazell and Pachauri, 2006].

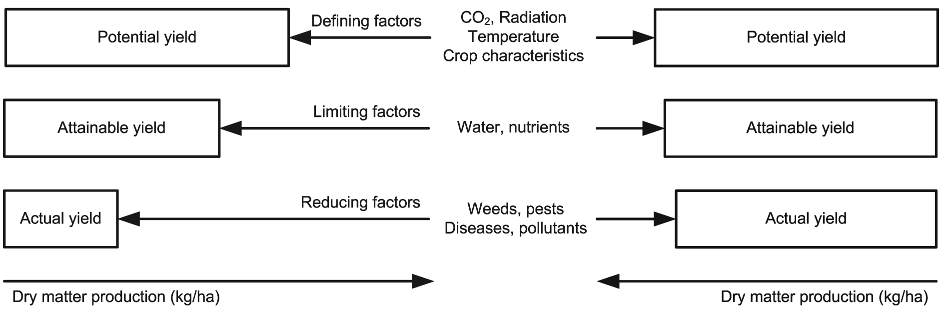
The conversion of biomass to secondary energy can be expressed both in mass and in energy. The energy content of fuels is expressed either by the higher heating value, or the lower heating value. The *higher heating value* includes all of the heat released from the fuel, including the latent heat of vaporization of water vapor which is formed during combustion [IEA, 2005] [Blok, 2006]. The *lower heating value* excludes the latent heat of vaporization of the water vapor that is formed during combustion [IEA, 2005] [Blok, 2006].

2.3 Agriculture system

The agriculture system, including forestry, grows crops which produce biomass. This research considers two agricultural systems: the current system and the HEI-system. The first refers to the current agricultural practice and current actual yield of a country. The second refers to an agricultural practice where high external inputs (HEI) are used and it's corresponding higher (actual) yield.

The actual yield is determined by three production situations, these situations vary in space, in time, per crop, and per agricultural practice. Growth-defining factors, growth-limiting factors, and growth-reducing factors distinguish three production situations. Figure 2.2 shows for both current and HEI-system these production situations, with their respective factors.

Figure 2.2: Actual yield of two production systems with their influencing factors.



(a) current system (b) HEI-system

Modified from: [Ivens et al., 1992]

The first production situation achieves the potential yield of the crop, which is the theoretical maximum. Here crops have ample water and nutrients and are free of weeds, pests and diseases. The growth rate is only governed by the current state of the crop and the defining factors: CO_2, solar radiation, temperature and crop characteristics. The second production situation concerns the attainable yield. Here water shortage, or water shortage and nutrient shortage limit the yield of crops. The third production situation concerns the actual yield. Here the effects of weeds, pests, diseases, and pollutants determine the yield of crops [Ivens et al., 1992].

The HEI-system uses a high amount of additional inputs, such as fertilizers. As a result this system achieves (actual) yields which are close to the potential yield. The current system uses less inputs and therefore has a lower actual yield. The difference between the two actual yields depends on the difference between the growth-limiting factors and growth-reducing factors of the two systems.

Crops produce dry biomass, which is distributed over various plant organs. Most notably is the economic yield, together with crop residues this is the total biological yield. In the example of wheat the economic yield is grain, and crop residues are the leaves, stems and roots. The ratio of economic yield and total biological yield is defined as the *harvest index* [Gerbens-Leenes and Nonhebel, 2004].

Bioenergy is derived from biomass. Primary energy is the total biological yield. Secondary energy is produced with either first or second generation conversion processes. First generation conversion technologies focus on the economic yield, while second generation conversion technologies open up possibilities for the use of crop residues.

2.4 Water system

The growth of plants requires water. Therefore the production of biomass requires water. This causes that bioenergy requires water and that the consumption of bioenergy corresponds with water consumption. The growth of plants requires water on a day by day basis [Allen et al., 1998], this water demand can be calculated with the model CropWat [Clarke, 1998] [FAO, 2008].

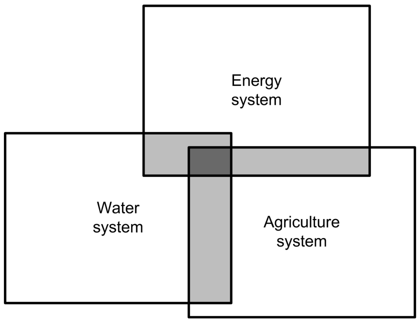
The water footprint method integrates the daily water demand over the cultivated period of a crop. This results in the virtual water content of a crop. The *virtual water content* of a product (a commodity, good or service) is the volume of freshwater used to produce the product, measured at the place where the product was actually produced [Hoekstra and Chapagain, 2008]. The virtual-water content of a product consists of three components, namely a green, blue and grey component. The *blue virtual-water content* of a product is the volume of surface water or groundwater that evaporated as a result of the production of the product. Examples are: irrigation water which is consumed by crops, or surface water which evaporates in the cooling towers of a power plant. The *green virtual-water content* of a product is the volume of rainwater that evaporated during the production process. The *grey virtual-water content* of a product is the volume of water that becomes polluted during its production [Hoekstra and Chapagain, 2008].

The total consumption of products associates therefore with a water consumption, this is the water footprint. The *water footprint* of an individual or community is the total volume of freshwater that is consumed to produce the goods and services consumed by the individual or community [Hoekstra and Chapagain, 2008]. When energy is derived from biomass, energy consumption generates a water footprint that can be calculated using the water footprint methodology.

2.5 The water footprint of energy from biomass

When biomass is grown for energy purposes, the energy system, the agricultural system, and water system meet. Figure 2.3 shows the overlap between these systems. This overlap is the water footprint of energy from biomass. Here the water footprint of energy from biomass of an individual or community refers to the total volume of freshwater that is consumed to produce the bioenergy services consumed by the individual or community. Here bioenergy services are energy services produced from primary or secondary bioenergy carriers.

Figure 2.3: Overlap between the water system, agriculture system, and energy system.



Chapter 3

Methodology

3.1 Introduction

The water footprint methodology [Hoekstra and Chapagain, 2007] assesses the water footprint of crops. This study adopts this method. The interaction between water and bioenergy is assessed with the water footprint methodology.

Figure 3.1: Flow chart of the assessment of the water footprint of bioenergy

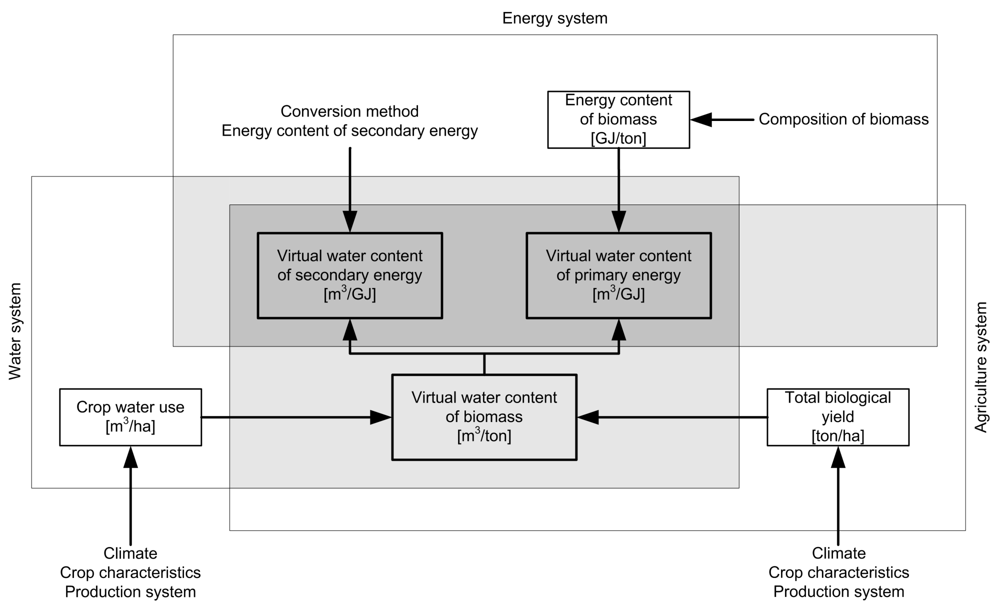


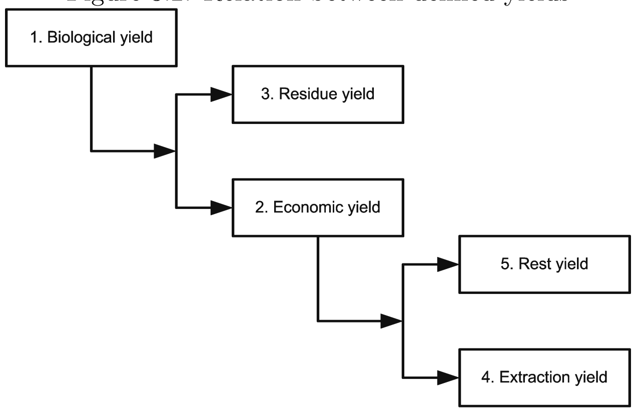
Figure 3.1 shows the energy, agriculture, and water system. The overlap of the three systems contains the virtual water content of energy. The chapter contains four sections. These are section 3.2 the method for energy, section 3.3 the method for agriculture, section 3.4 the method for water, and section 3.5 the method for the water footprint of bioenergy. The first section describes the calculation of the energy content of biomass, the conversion of biomass into

secondary energy, and the current consumption of bioenergy. The second section describes the calculation of the total biological yield and lists characteristics on the crop cultivation. The third section describes the calculation of the crop water use. The last section describes the calculation of the virtual water content of biomass, primary energy, secondary energy and the water footprint of bioenergy.

3.1.1 Yields in the research

The total biological yield was defined in the previous chapter as the sum of the economic yield and the crop residues. This research defines five yields (DM). Figure 3.2 shows the relation between the five defined yields.

Figure 3.2: Relation between defined yields



1. Total biological yield ($Y_{biological}$, $DM\ ton/ha$) is the sum of the economic yield and the crop residues.

2. Economic yield ($Y_{economic}$, $DM\ ton/ha$) is the part of a crop that provides the economic benefit when it is grown for food or feed purposes, such as the grain of wheat.

3. Residue yield ($Y_{residue}$, $DM\ ton/ha$) is the non-economic part, such as the stems and leaves of wheat.

4. Extraction yield ($Y_{extraction}$, $DM\ ton/ha$) is the valuable part in the economic yield that can be extracted, such as sugar in the sugarbeet or oil in oil palm fruit.

5. Rest yield (Y_{rest}, $DM\ ton/ha$) is the part of the economic yield which is not the extraction yield, such as beet pulp of sugarbeet.

Table 3.1 shows three yields per crop which are included in this study. Mesocarp oil is palm oil that is extracted from the fleshy oil palm fruit, this excludes the kernel and kernel oil. Round wood is wood in its natural state when felled. This study doesn't use an extraction yield for trees.

Table 3.1: Crop parts per yield

Crop	extraction yield $Y_{extraction}$	economic yield $Y_{economic}$	residue yield $Y_{residue}$
Wheat	starch	ear, grain	stem, leaves
Maize	starch	cob, grain	stem, leaves
Sorghum	starch	ear, grain	stem, leaves
Sugarbeet	sugar	sugarbeet	stem, leaves
Sugarcane	sugar	stalk	leaves
Soy	soy oil	seed	stem, leaves
Rape	rape oil	seed	stem, leaves
Oil palm	mesocarp oil	fruit bunch	stem, foliage
Eucalyptus	-	round wood	foliage
Pine	-	round wood	foliage
Poplar	-	round wood	foliage

Analog to the harvest index ($Y_{economic}/Y_{biological}$), this research defines the extraction index (EI, $-$), the ratio between the extraction yield and the economic yield. Equation 3.1 shows the relation between the economic yield, the harvest index and the biological yield. Equation 3.2 shows the relation between the extraction yield, the extraction index and the harvest yield.

$$Y_{economic} = HI * Y_{biological} \tag{3.1}$$

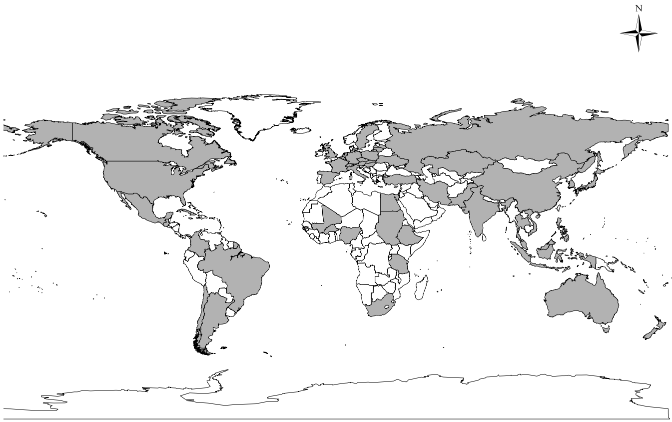
$$Y_{extraction} = EI * Y_{economic} \tag{3.2}$$

The harvest index and extraction index refer to crops in the field. Harvest of the crop and extraction of valuable parts results in losses. This research neglects these losses. The harvest index and fraction index therefore refer to both the composition of the crop as well as the yields of both harvest and extraction. Appendix D tables D.1 and D.2 show the harvest and extraction indices which are used in this study.

3.1.2 Countries in the research

This research includes 50 countries, these are selected in a way that: 1) together they have a production share of 90% or more for each of the starch crops, sugar crops, and oil crops, 2) they have a consumption share of 90% or more for the liquid biofuels ethanol and biodiesel. Table and figure 3.2 show the selected countries.

Table 3.2: Included countries by region



Region	Countries
Africa	Burkina Faso, Egypt, Ethiopia, Mali, Nigeria, South Africa, Sudan, Tanzania
America, Latin	Argentina, Brazil, Chile, Colombia, Cuba, Guatemala, Mexico
Asia, East	China, Korea
Asia, South	India, Pakistan
Asia, South East	Indonesia, Malaysia, Philippines, Thailand, Viet Nam
Canada	Canada
Europe, East	Czech Republic, Hungary, Poland, Slovakia
Europe, OECD	Austria, Belgium, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland, United Kingdom
Former Russia	Kazakhstan, Latvia, Lithuania, Russian Federation, Ukraine
Japan	Japan
Middle East	Iran, Turkey
Oceania	Australia, New Zealand
USA	United States of America

3.2 Method for energy

3.2.1 Energy content of biomass

The energy content of a fuel can be expressed as the heating value (HHV or LHV). This research expresses energy from biomass in terms of higher heating value. Crops show variability in composition, therefore the heating value varies. This research uses a hypothetical crop composition based on existing crops and a corresponding heating value, based on the method from [Gerbens-Leenes et al., 2008]. Six components dominate the dry matter composition. These are: carbohydrates, fats, lignins, minerals, organic acids, and proteins. Appendix C table C.1 shows the heating value these components. The study calculates the heating value of biomass by combining the heating value of each component and the mass distribution.

This research selects a mass distribution which corresponds with a crop or crop part for the economic, extraction, and residue yield. Table 3.3 lists the names of these mass distributions. Appendix C table C.2 lists components for each mass distribution.

Equation 3.3 shows the calculation of the heating value of the total biological yield ($e_{biological}$, $GJ\ HHV/DM\ ton$) as a function of the heating value of the economic yield ($e_{economic}$), residue yield ($e_{residue}$), and the harvest index (HI). Equation 3.4 shows the calculation of the heating value of the rest yield (e_{rest}, $GJ\ HHV/DM\ ton$) as a function of the economic yield ($e_{economic}$), extraction yield ($e_{extraction}$), and the extraction index (EI).

$$e_{biological} = HI * e_{economic} + (1 - HI) * e_{residue} \tag{3.3}$$

$$e_{rest} = \frac{e_{economic} - EI * e_{extraction}}{(1 - EI)} \tag{3.4}$$

Table 3.3: Mass distributions of yields per crop

Crop	extraction yield $Y_{extraction}$	economic yield $Y_{economic}$	residue yield $Y_{residue}$
Wheat	carbohydrates	wheat	stems
Maize	carbohydrates	maize	stems
Sorghum	carbohydrates	sorghum	stems
Sugarbeet	carbohydrates	whole beet	leaves
Sugarcane	carbohydrates	whole tops	leaves
Soy	fats	soy	stems
Rape	fats	sunflower	stems
Oil palm	fats	sunflower	stems
Eucalyptus	-	stems	leaves
Pine	-	stems	leaves
Poplar	-	stems	leaves

3.2.2 Secondary energy

Secondary energy refers to energy carriers which are derived from these primary energy carriers. Primary energy carriers are the total biological yield[1] This

[1] Primary energy carriers are energy carriers which are directly extracted from natural resources [IEA, 2005]. The economic yield of crops fits this definition. However the calculation

research contains two transformation cases: first and second transformation.

First transformation

First transformation consists of three processes, harvest of biomass, extraction of valuable parts from biomass, and conversion of these valuable parts into secondary energy carriers. This research includes the following first generation processes:

- fermentation of starch for the production of ethanol
- fermentation of sugar for the production of ethanol
- trans-esterfication of oil for the production of biodiesel
- slow pyrolysis of round wood for the production of charcoal
- combustion of oil for the production of electricity
- combustion of round wood for the production of electricity

For the conversion of biomass into secondary energy this study defines the conversion index, the ratio between yield of secondary energy carriers and the extraction yield ($CI =$ secondary energy carrier/$Y_{extraction}$). The conversion indices of fermentation and trans-esterfication are the theoretical yields. Appendix C table C.3 lists all conversion indices.

The transformation of total biological yield into the secondary energy carrier produces several byproducts. Oil is extracted from the economic yield of oil crops. This produces the following byproducts: press cake from soybeans, press cake from rapeseed, and kernels from oil palm fruit[2]. These have a high monetary value and can therefore not be neglected. Multiple ways can be used to credit a by product. This research expresses the value of byproducts by energy, this is the energy equivalent (e_{eq}, $GJ\ HHV/DM\ ton$). Other byproducts have considerably less monetary value and are therefore neglected.

Examples of other byproducts are: Dry Distillers Grains (DDG) for the production of ethanol from maize, beet pulp of the extraction sugar from sugarbeet, and glycerol for the production of biodiesel from any oil. The value of DDG is less than 10% of the value of ethanol [Pimentel and Patzek, 2005]. The value of beet pulp and glycerol can be fully ignored [Chapagain and Hoekstra, 2004] [Pimentel and Patzek, 2005].

Second transformation

Theoretically enzymatic fermentation can convert all types of carbohydrates into ethanol. Second transformation converts byproducts into ethanol.

The sum of all secondary energy carriers (ethanol and biodiesel) and the energy equivalent of valuable byproducts is the total energy yield (e_{tey}, $GJ\ HHV/DM\ ton$). The total energy yield refers to the yield per $DM\ ton$ total biological yield. Calculation of the total energy yield varies by crop category. The total energy yield

procedure considers the total biological yield as the starting point.

[2]The rest yield of oil palm also contains the empty fruit bunch, this is not included in this study.

of starch crops, sugar crops, and trees consists of ethanol from all carbohydrates in the economic and residue yield. The total energy yield of oil crops consists of biodiesel, the energy equivalent of valuable byproducts, and ethanol. The extraction yield, which is oil, converts into biodiesel with trans-esterfication. The carbohydrates in the residue yield convert into ethanol by enzymatic fermentation.

The conversion index of enzymatic fermentation is the theoretical yield. Appendix C table C.3 lists the conversion indices. Appendix C table C.2 lists the carbohydrate fraction of crop parts.

3.2.3 Consumption of bioenergy in 2005

The research considers three groups of bioenergy consumption: 1) liquid biofuels derived from crop categories 1-3, 2) wood fuels derived from crop category 4, 3) fuels from other sources, mainly derived from residues. Residues are of minimal importance in the water footprint methodology. This study therefore excludes the last group.

The International Energy Agency (IEA) keeps statistics on the energy and bioenergy consumption volume of (all) countries in the world. The open access part reports liquid biofuels as one cluster. Annual surveys of the IEA distinguish three types of liquid biofuels: biodiesels, biogasoline, and other liquid biofuels. [IEA, 2007] reports these for the year 2005 on a LHV basis. This research uses this source for the consumption volume of liquid biofuels. This research treats the data on liquid biofuels in the following way: 1) liquid biofuels are produced by first generation conversion technologies, 2) biodiesels are treated as biodiesel, 3) biogasoline is treated as ethanol, 4) other liquid biofuels in Brazil are treated as ethanol, other liquid biofuels from other countries are excluded from this research, and 5) values are increased by 10% to approximate the higher heating value. Dufey (2006) gives a literature review on liquid biofuels and their feedstock. This research uses this source as a basis for the feedstock of liquid biofuels.

The Forestat database is a part of the Faostat database of the FAO [FAO, 2007a]. This contains annual data for more than 200 countries on wood production and trade. Of wood production it contains it's (end) use, such as coniferous fuelwood, non-coniferous fuelwood, and wood charcoal. Fuelwood is reported as volume of wood (m^3), wood charcoal is listed as mass of charcoal (ton). The Forestat lists no trade for coniferous and non-coniferous fuelwood, it does list trade of wood charcoal. This research uses this source for the consumption of heat and power derived from wood. It uses the data on fuelwood in the following way: 1) coniferous fuelwood is treated as pine roundwood, 2) non-coniferous fuelwood in countries with a tropic or sub-tropic climate is treated as eucalyptus roundwood, 3) non-coniferous fuelwood in countries with a temperate and boreal climate is treated as poplar roundwood, and 4) energy consumption is calculated with the energy content of round wood and the dry mass density of round wood.

This research treats the data on wood charcoal in the following way: 1) wood charcoal is produced by first generation conversion technologies, 2) wood charcoal is produced from the most water efficient fuelwood species in a country, and 3) energy consumption is calculated with the energy content of charcoal. Equation 3.5 shows the calculation of wood charcoal consumption. For some countries this gives negative consumption values, wood charcoal consumption of these countries is excluded.

$$consumption = production + import - export \tag{3.5}$$

3.3 Method for agriculture

3.3.1 Crops in the research

Crops can be divided into different categories according to their chemical composition or their function. A division can be made into food and non-food crops. This research defines four categories: 1) starch crops, 2) sugar crops, 3) oil crops, and 4) woody crops (trees). This research analysis eleven crops.

Starch crops are crops which contain a high amount of starch (cereals and tubers). Cereals are used more commonly for the production of liquid biofuels [Dufey, 2006]. Wheat is the most used cereal in the world, followed by rice. Both crops are used predominantly for food. In developed countries coarse grains as maize and sorghum are mainly used for animal feed (60%), but in developing countries 80% of these grains are used for food [FAO, 2002]. For production of ethanol from cereals, maize is the most common feedstock [Dufey, 2006]. Wheat and sorghum are less common [Dufey, 2006], but are added to the research to get a global cereal coverage.

Sugar crops are crops which contain a high amount of sugar (sugarcane and sugarbeet). Sugarcane is most commonly used for ethanol production, with Brazil as leading example [Dufey, 2006]. Sugarcane grows in tropical climates, whereas sugarbeet grows in temperate climates [Fischer et al., 2000]. Both crops are included to get a global sugar crop coverage.

Oil crops are crops which contain a high amount of oil. Soy, rape, sunflower and oil palm together account for more than three quarters of the world's oil-seed production [FAO, 2002]. Of these four crops soy, rape and oil palm are added to this research, as these are more frequently reported as basis for biodiesel [Dufey, 2006].

Woody crops are crops of which wood makes up a large fraction of the biomass. Pine, eucalyptus and poplar are three of the most common tree species. This is true for both natural forests [FAO, 2006a] and plantations [Del Lungo et al., 2006]. Poplar and eucalyptus are less common than pine, yet these are on top of the list of desirable short rotation wood crops [Hohenstein and Wright, 1994].

- Food crops:
  - 1) Starch crops:
    - Wheat (*Triticum spp.*)
    - Maize (*Zea mays L.*)
    - Grain sorghum (*Sorghum bicolor L.*)
  - 2) Sugar crops:
    - Sugarbeet (*Beta vulgaris L.*)
    - Sugarcane (*Saccharum officinarum L.*)
  - 3) Oil crops:
    - Soy (*Glycine max L. Merr.*)
    - Rape (*Brassica napus L.*)
    - Oil palm (*Elaeis guineensis Jacq.*)
- Non-food crops:

- 4) Trees:
  - Eucalyptus (*Eucalyptus spp.*)
  - Pine (*Pinus spp.*)
  - Poplar (*Populus spp.*)

3.3.2 Total biological yield

The total biological yield ($Y_{biological}$, $DM\ ton/ha$) is a function of both the harvest index (HI, $-$) and the economic yield ($Y_{economic}$, $DM\ ton/ha$). Equation 3.6 shows the calculation of the total biological yield.

$$Y_{biological} = \frac{Y_{economic}}{HI} \tag{3.6}$$

This study considers two production systems.

1. The current global production system of crop categories 1-4
2. A theoretical high external input (HEI) production system for crop categories 1-3

Current system

The faostat database of the Food and Agriculture Organization of the United Nations [FAO, 2007a] contains annual production data for more that 200 countries of a large number of crops. This research derives data on yields from the Faostat database. This research calculates the average over the period $1997 - 2001$.

The Faostat database reports yields ($Y_{reported}$, ton/ha) as fresh weight. Therefore these values are corrected with a correction factor ($f_{correction}$,$-$), which is the dry matter content. Equation 3.7 shows the calculation of the dry economic yield ($Y_{economic}$, $DM\ ton/ha$) from the reported yield. Appendix D table D.3 lists these correction factors.

$$Y_{economic} = f_{correction} * Y_{reported} \tag{3.7}$$

Natural forests supply most of the wood which is consumed [FAO, 2006a]. Besides producing wood, natural forests also have other functions, such as erosion control, harboring wild life, and the regulation of water runoff. This research assumes that the production system of a plantation with a productive function is most suitable to measure the relation between water and the production of wood.

The database of the Global Planted Forest Assessment 2005 (GPFA) of the FAO [FAO, 2007c] reports the economic yield of wood combined with the rotation/growth period, or the mean annual increment in volume of growing stock per year ($m^3/ha/yr$) of planted forests. This contains both planted forests with a productive and protective function. Yields are reported per (sub-) genus or taxa for 60 countries. This research uses the yields of trees of planted forests with a productive function from the GPFA database.

The GPFA database reports the volume of wood ($Y_{reported}$, $m^3/ha/yr$). Therefore these values are corrected with a correction factor ($f_{correction}$, $DM\ ton/m^3$), which is the dry mass density of wood. Appendix D table D.4 lists these correction factors.

This research excludes yields of 0 $m^3/ha/yr$. When the GPFA database reports multiple taxa of the same (sub-) genus for a country, this research uses the average yield. For example United Kingdom reports both Pinus contorta and Pinus sylvestris. This research uses the average value of these two taxa for the yield of pine trees.

HEI system

The Global Agro-ecological Zones study (GAEZ) of the FAO [Fischer et al., 2000] has calculated the average crop yields per country as a function of the crop characteristics, the climate in a country, the soil inventory of a country, the amount of external input, and the application of irrigation. This research takes the modeled yields of starch crops, sugar crops, and oil crops from the GAEZ research which correspond with: 1) production under high external input, 2) production under irrigation, 3) production on very suitable to mediocre suitable land, and 4) production in countries that also report yields in the period $1997-2001$ in the Faostat database.

The GAEZ study reports crop yields ($Y_{reported}$, $DM\ ton/ha$) which either match the economic yield or the extraction yield. In the latter case the reported yields are corrected with a correction factor ($f_{correction}$,$-$). Appendix D table D.5 lists these correction factors.

3.3.3 Crop cultivation

Production systems cultivate crops in different ways, resulting in large differences in yields among countries. Also within the current production system large differences occur between one country and another. There are four factors that strongly influence water consumption of a crop:

- location of crop cultivation
- start and length of the cultivation period
- irrigation
- fertilizer application

Current system of crop categories 1-3

I Location of crop cultivation This research assumes that the cultivated area of a crop within a country has a uniform climatic regime. Therefore crop cultivation uses one location per country. Information on crop locations derive from: 1) Major world crops areas and climatic profiles [USDA, 1994], 2) 18 major crop area maps of the early 1990's [Leff et al., 2004], and 3) the location of the capital [CIA, 2007].

Crop cultivation occurs in regions with or without irrigation. In that case this research selects two locations when the regions are equal in size, or three locations when one region is twice the size of the other.

II Start and length of the cultivation period This research uses three ways to determine the start of the cultivation period: 1) Major world crops areas and climatic profiles [USDA, 1994], 2) the start of the growth period, or 3) the first of January. A concept from the AEZ methodology determines the start of the growth period. This sets two conditions: average temperature should be higher than 5^oC and the precipitation should be higher than at least half the potential evapotranspiration [FAO, 1996]. The start of the cultivation uses the middle ($15th$) of the first month which meets both criteria.

Crop yield data of annual crops refers to the yield per cultivation period. The cultivation period (LGP, $days$) varies for annual crops by crop and climate. Crop yield data of perennial crops refers to the yield per year. The cultivation period of these crops is therefore 365 days. Appendix D table D.7 lists the cultivation periods.

For most crops the cultivation period coincides with the growth period. An exception is winter wheat, cultivation of winter wheat starts some time before the winter. When data on the cultivation of these crops are available this research models them as winter crops. Otherwise this research models the crops as spring varieties, cultivation of these plants starts at the beginning of the growth period.

III Irrigation Crop land which is equipped for irrigation covers a fraction of the crop land, this is f_{iA} $(-)$. This research calculates a country wide average of the f_{iA} per crop. It uses three global maps/sources: 1) Global Map of Irrigation Areas version 4.0.1. [Siebert et al., 2007], 2) 1992 global croplands data v1.1 [Ramankutty and Foley, 1998], and 3) 18 Major Crops Dataset [Leff et al., 2004].

The first source contains information on the amount of irrigation per grid cell. The second contains information on the permanent crop land in a cell. This research assumes that only permanent crop land is irrigated. Combining these sources gives the irrigation of permanent crop land. The third source contains multiple maps, each map shows the cultivation area for one crop. This research assumes that irrigation within one grid cell is homogenously distributed. Calculation of the f_{iA} uses the weighed intersection between this map and the map on irrigation of permanent crop land.

IV Fertilizer application The Fertistat database from the FAO [FAO, 2007b] is the database version of the 'Fertilizer use by crop' series from the FAO. This contains information on the application rate of (inorganic) fertilizer, the size of the area where fertilizer is applied, and the national consumption of fertilizer for 30 crops and for 100 countries. This research derives information on nitrogen from that database. This research excludes excessive application rates or improves these with the individual reports from the 'Fertilizer use by crop' series.

Not all farmers in all countries have access to, or are willing to use fertilizer. This research uses two methods to calculate the national average nitrogen use (N_{use}, $kg\ N/ha$) of a crop. The first method assesses the nitrogen application rate (N_{rate}, kg/ha) of farmers that use fertilizer and the area fraction they possess (f_{fA}, $-$). This area fraction is calculated with their area ($A_{fertilized}$, ha) and the total area for this crop (A_{total}, ha). The second method assesses the national consumption of nitrogen for a crop ($N_{consumption}$, kg) and the total area for this crop (A_{total}, ha). Equations 3.8 and 3.9 show these two methods.

$$N_{use} = N_{rate} * f_{fA} = N_{rate} \frac{A_{fertilized}}{A_{total}} \tag{3.8}$$

$$N_{use} = \frac{N_{consumption}}{A_{total}} \tag{3.9}$$

This research calculates the N_{use} in the following ways:

- Equation 3.8 with the nitrogen application rate (N_{rate}, $kg\ N/ha$) of farmers that use fertilizer and the area fraction they possess (f_{fA}, $-$) both given in Fertistat.
- Equation 3.8 with the nitrogen application rate (N_{rate}, $kg\ N/ha$) of farmers that use fertilizer, the area they possess ($A_{fertilized}$, ha) both given in Fertistat, and the total area for this crop (A_{total}, ha) in $1997-2001$ given in Faostat.
- Equation 3.9 with the national consumption of nitrogen for a crop ($N_{consumption}$, $kg\ N$) and the total area for this crop (A_{total}, ha) in $1997-2001$ given in Faostat.

This research calculates for each country the ratio between average nitrogen use and the total biological yield. The weighted average of the ratio of a crop is the parameter a ($kg\ N/DM\ ton$). The weighted average uses the production volume of the crop in the period $1997-2001$ of the included countries. Countries which are not included in the Fertistat database use an estimate for the N_{use} of their crops. This estimate uses the following function: $N_{use} = a * Y_{biological}$.

Current system of trees

For trees the GPFA database does not report the location of planted forests. This research therefore uses the location of the capital for the location of crop cultivation in a country. Trees are perennial crops. The yield data in the GPFA database corresponds with the average production per year. Therefore this research uses a cultivation period of 365 *days* which starts at the 1st of January. Further this research assumes that irrigation for trees is negligible.

Similar to other crops, trees need to be fertilized to maintain high yields and fertility of the soil [Wright, 1994]. This research uses a fixed ratio between the nitrogen use and the total biological yield. This ratio is a nitrogen use of 100 $kg\ N/ha/yr$ for an economic yield of 10 $DM\ ton/ha/yr$ [IEA, 1994].

HEI system

This research assumes that the location of crop cultivation in the HEI system is the same as in the current production system. Further this research assumes that the start and the length of crop cultivation in this system are the same as in the current production system. Moreover the yields in the HEI production system correspond with irrigation, therefore f_{iA} is 100%.

HEI systems have a large fertilizer input and consequently high yields. Nitrogen use of crops is equally efficient for low as for high yields [de Wit, 1992]. Therefore there is a fixed ratio between nitrogen use and the total biological yield. Differences exist between the nitrogen uptake of the crop and the nitrogen applied by the farmer. This research assumes that other sources of nitrogen application can be ignored. It also assumes that the HEI system is equally efficient as current high external input. It takes the ratio between nitrogen use and total biological yield of a country that: 1) is reported in the Fertistat database, 2) fertilizes close to 100% of it's area, and 3) reports high yields. Table 3.4 lists the selected countries.

Table 3.4: Countries basis for fertilizer consumption in the HEI-system.

Crop	selected country
Wheat	Belgium
Maize	Belgium
Sorghum	Unites States
Sugarbeet	Belgium
Sugarcane	Australia
Soy	Unites States
Rape	Czech Republic
Oil palm	Malaysia

3.4 Method for water

The crop water use (CWU, m^3/ha) contains a green, blue, and grey component. These depend on the water demand, precipitation, irrigation, and pollution. This research includes pollution caused by the leeching of nitrogen into the surface water. Calculation of the green, blue, and grey water is based on the water footprint methodology [Hoekstra and Chapagain, 2008]. Appendix E section E.1 presents this methodology.

3.4.1 Current system of crop categories 1-3

The calculation of the blue and green crop water use of the current global production system of crop categories 1-3 uses the water footprint methodology. The CRU CL 2.0 database [New et al., 2002] contains global weather data which is spatially interpolated between weather stations. Weather data consist of monthly values which are 30 year averages. For the calculation of the water footprint this research uses weather data from the CRU CL 2.0 database.

Together the available green and blue water make up for the water supply for the crop. Errors in the methodology can cause an underestimation of the water supply, which results in large errors in further parameters such as the virtual water content. This research excludes values when the water supply is lower than 40% of the crop water requirement of the whole cultivation period.

3.4.2 Current system of crop category 4

Water management of trees deviates from the other crops. They have a different run-off, evaporate water different, and store water different from crops such as wheat. Therefore the method for calculation of the water consumption of crop category 4 deviates from the method for crop categories 1-3. Differences in the methodology are:

- water demand uses an adapted function
- water availability is not a restricting factor

Complex and simple models exist for the water demand of trees. This research uses a simple model for the water demand. Calculation uses a formula for evapotranspiration [Shuttleworth, 1993]. Equation 3.10 shows this calculation of the daily water demand or crop water requirement (CWR, mm/day).

$$CWR = 0,8 * ET_{rc}^{forest} + \alpha_i * P \tag{3.10}$$

This is a combination of the evapotranspiration of the tree (ET_{rc}^{forest}, mm/day) and evaporation of intercepted rainwater. The evapotranspiration of the tree is calculated with Penman-Monteith formula and is evapotranspiration of the reference crop, but modified with the albedo value of forests. Appendix table E.18 lists the albedo values. Intercepted rainwater depends on the intercepted fraction of rain water (α_i, $-$) and the amount of rain (P, mm/day). The α_i is a low value for dedicious trees, and a low value in climates which have short, but intense rain showers [Shuttleworth, 1993]. This research assumes that tree species have strong ties with the factors which govern the α_i. Therefore a tree species uses only one value for the α_i. Appendix table E.19 lists these values.

Evapotranspiration of water uses energy. This research limits this energy use in one month to 90% of the net radiation. This is the suggested limit for extensive forests [Shuttleworth, 1993]. Further calculation of the CWU uses the described methodology for the crop water use. Section 3.3.3 describes the other inputs for the formulas.

3.4.3 HEI system

The calculation of the blue and green crop water use of this system also uses the described methodology for the crop water use. Section 3.3.3 describes the inputs for the formulas.

3.5 Method for the water footprint of bioenergy

3.5.1 Virtual water content of primary energy

The virtual water content of primary bioenergy is the volume of water that is used to produce one unit of primary bioenergy. The calculation is done in two steps. The first step calculates the virtual water content of total biological yield ($v(biological)$, $m^3/DM\ ton$). This is a combination of the total biological yield ($Y_{biological}$, $DM\ ton/ha$) and the volume of water which was used to produce it, the crop water use (CWU, m^3/ha). Equation 3.11 shows the calculation.

$$v(biological) = \frac{CWU}{Y_{biological}} \tag{3.11}$$

The second step calculates the virtual water content of primary energy $v(primary\ energy)$, $m^3/GJ\ HHV$). This uses the result of step 1 and adds the energy content of the total biological yield ($e_{biological}$, $GJ\ HHV/DM\ ton$). Equation 3.12 shows the calculation of the virtual water content of primary energy.

$$v(primary\ energy) = \frac{v(biological)}{e_{biological}} \tag{3.12}$$

Not all cases value the total biological yield. In the case of fuelwood the round wood is valued and the foliage is generally discarded. Calculation of the virtual water content of this primary energy uses not the biological yield, but the economic yield. Equation 3.13 shows the calculation of the virtual water content of primary energy in these cases. This can be rewritten into equation 3.14, calculation of the virtual water content of secondary energy uses a similar shape.

$$v(primary\ energy) = \frac{CWU}{Y_{economic} * e_{economic}} \tag{3.13}$$

$$v(primary\ energy) = \frac{v(biological)}{HI * e_{economic}} \tag{3.14}$$

3.5.2 Virtual water content of secondary energy

Accounting the virtual water content of a product that is converted into a new product uses the product fraction (f_p, $DM\ ton/DM\ ton$) and the value fraction (f_v, \$/\$). The product fraction is defined as the amount of processed product (W, $DM\ ton$) obtained per amount of root product. The value fraction is defined for a processed product as the ratio of the market value of the product to the aggregated market value of all the products obtained from the root product. This is based on the market value per unit product (V_p, \$/ton) and the amount of product (W_p, ton). The calculation of the product fraction, value fraction is shown in equations 3.15 and 3.16.

$$f_p(p) = \frac{W_p}{W_r} \tag{3.15}$$

$$f_v(p) = \frac{W_p * V_p}{\sum_{i=1}^{n} W_i * V_i} \tag{3.16}$$

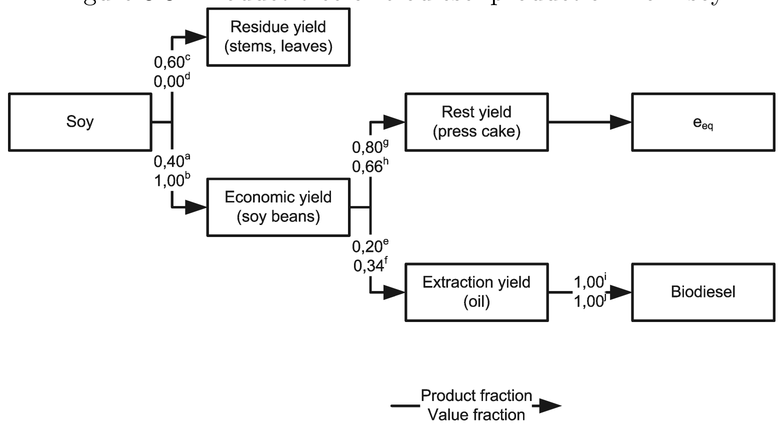
Equation 3.17 shows the calculation of a the virtual water content of a new product ($v(new)$, $m^3/DM\ ton$) based on a root product.

$$v(new) = v(root) * \frac{f_v(new)}{f_p(new)} \tag{3.17}$$

First transformation

The first transformation consists of multiple processes: harvest, extraction, and conversion. Figure 3.3 shows this for the production of biodiesel from soy. The figure lists for each of the processes the value and product fractions and labels these with the characters $a - j$.

Figure 3.3: Product tree of biodiesel production from soy



Calculation of the virtual water content of the products of each of these processes uses the product and value fraction. The last process calculates the virtual water content of a secondary energy carrier ($v(secondary)$, $m^3/DM\ ton$). Equation 3.18 shows the calculation of the virtual water content of secondary energy carrier per unit energy ($v(secondary\ energy)$, $m^3/GJ\ HHV$). This uses the heating value of a secondary energy carrier ($e_{secondary}$, $GJ\ HHV/DM\ ton$).

$$v(secondary\ energy) = \frac{v(secondary)}{e_{secondary}} \tag{3.18}$$

This research uses data on value fractions from [Chapagain and Hoekstra, 2004]. Appendix table F.1 lists the value and product fractions of the production of secondary energy carriers in the first transformation. The labels $a - j$ in the appendix table correspond with figure 3.3. Calculation of the virtual water content of secondary energy carrier per unit energy ($v(secondary\ energy)$, $m^3/GJ\ HHV$) can be done with one large step. Equation 3.19 shows the calculation of this 'large' step. This uses the aggregated product fraction $f_p(secondary)$ which refers to the total mass of secondary energy carriers which is obtained from one $DM\ ton$ of biological yield. Calculation does not use the value fraction, but uses the energy equivalent (e_{eq}, $GJ\ HHV/DM\ ton$) instead.

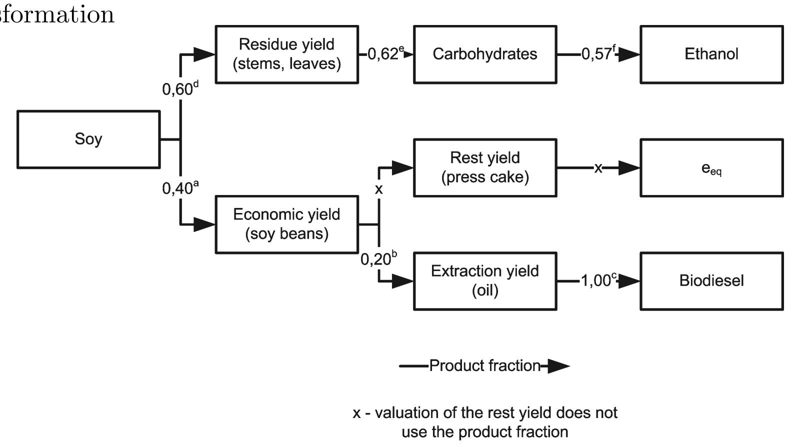
$$v(secondary\ energy) = \frac{v(biological)}{f_p(secondary) * e_{secondary} + e_{eq}} \tag{3.19}$$

This research chooses values for the energy equivalent in a way that the results of equations 3.18 and 3.19 match. Appendix table F.2 lists the aggregated product fractions and energy equivalents of the production of secondary energy carriers in the first transformation. Appendix table C.3 lists the energy content of secondary energy carriers.

Second transformation

The second transformation produces liquid biofuels from the whole plant. Calculation uses the total energy yield (e_{tey}, $GJ\ HHV/DM\ ton$) and the virtual water content of the biological yield ($v(biological)$, $m^3/DM\ ton$). The total energy yield is the value of all products which are produced from one $DM\ ton$ of total biological yield expressed by energy. This is a combination of biodiesel, ethanol, and energy equivalents. Figure 3.4 the product tree of soy with product fractions of individual processes. The figure labels these with the characters $a - f$.

Figure 3.4: Product tree of liquid biofuel production from soy with the second transformation



Appendix table F.3 lists the product fractions of second transformation. The labels $a - f$ in the appendix table correspond with figure 3.4. Equation 3.20 shows the calculation of the total energy yield. Here $f_p(biodiesel)$ and $f_p(ethanol)$ are aggregated product fractions and refer to the total mass of biodiesel and ethanol obtained from one $DM\ ton$ of biological yield.

$$e_{tey} = f_p(ethanol) * e_{ethanol} + e_{eq} + f_p(biodiesel) * e_{biodiesel} \tag{3.20}$$

The second transformation attributes water according to the energy value. Therefore the virtual water content of secondary energy expressed per unit energy is the same for all individual products. Equation 3.21 shows the calculation of the virtual water content of secondary energy ($v(secondary\ energy)$, $m^3/GJ\ HHV$) in second transformation.

$$v(secondary\ energy) = \frac{v(biological)}{e_{tey}} \tag{3.21}$$

Appendix table F.4 lists the aggregated product fractions and energy equivalents of second transformation. Appendix table C.3 lists the energy content of ethanol and biodiesel.

3.5.3 Water footprint of bioenergy consumption

The water footprint of bioenergy consumption is the volume of water relates to consumed volume. It depends on the volume of water which is used to produce one unit of bioenergy and the consumed volume of bioenergy. The water footprint methodology bases this consumed volume on the production location of a good. It then attributes water to countries or individuals based on trade patterns [Hoekstra and Chapagain, 2007]. However, no trade data are known on liquid biofuels or fuel wood. In 2005 the global trade in wood charcoal was less than 3% of it's production [FAO, 2007a]. This research does not include the trade in bioenergy as a whole. Countries which consume bioenergy are therefore the same as countries which produce biomass for bioenergy.

Equation 3.22 shows the calculation of the water footprint of bioenergy consumption ($WF(bioenergy)$, m^3/yr) of one source of bioenergy in one country. Here $c(bioenergy)$ is the consumption of bioenergy per year (GJ/yr) and $v(bioenergy)$ is the virtual water content of bioenergy (m^3/GJ).

$$WF(bioenergy) = c(bioenergy) * v(bioenergy) \tag{3.22}$$

The consumption of wood fuels is based on tree species and their virtual water content, selection of species varies by climate. For this the study uses the climate of the capital and the FAO thermal climate classification. Appendix D table D.6 lists this classification. The production of liquid biofuels and wood fuels uses crop categories 1-4. If a country contains no value for the virtual water content of a crop from crop category 1-3, this research uses the weighted average of that crop. The weighted average uses the production volume of the crop in the period 1997-2001 of the included countries. If a country contains no value for the virtual water content of a tree, this research uses the median value of that tree.

Chapter 4

Results and discussion

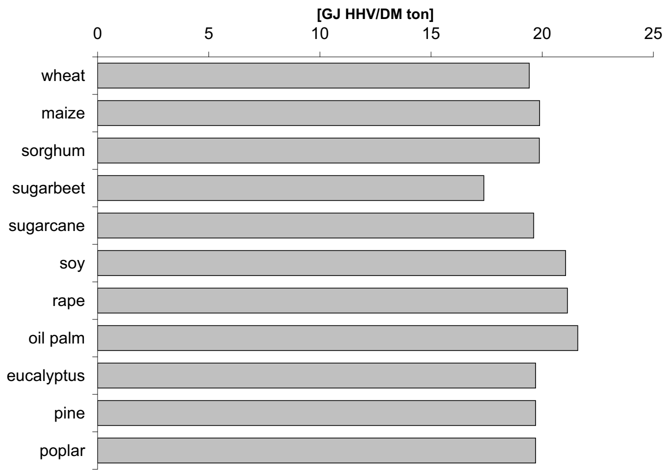
This chapter presents the results on the research on the water footprint of bioenergy. This chapter contains four sections: energy, agriculture, water, and water footprint of bioenergy results. Each section describes results for the current situation and optimal situation.

4.1 Energy results

4.1.1 Primary energy

Appendix G table G.1 lists the calculated heating values of the yield levels. Primary energy is the energy content of the total biological yield. Figure 4.1 shows the energy content of the total biological yield of crops. It shows that the energy contents of all crops are close to 20 $GJ\ HHV/DM\ ton$. Oil crops are slightly higher, while sugar crops are slightly lower.

Figure 4.1: Energy content of the total biological yield for seven crops and four trees



The figure shows the energy content of the total biological yield. Fuel wood is primary energy, but refers to the economic yield of a tree. This therefore excludes the leaves (residue yield). The heating value of fuelwood can be expressed per ton of fuelwood, this is 20 $GJ\ HHV/DM\ ton$. Fuelwood represents only 75% of the total biological yield. Therefore the heating value of fuelwood expressed per ton biological yield is 15 $GJ\ HHV/DM\ ton$.

4.1.2 Secondary energy

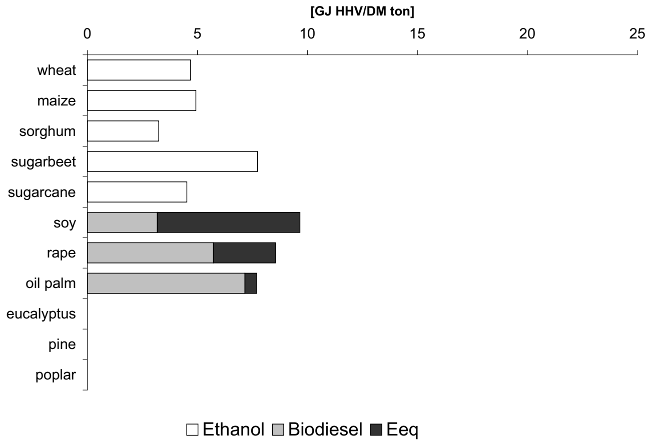
First transformation

Secondary energy refers to energy (carriers) which is produced from primary energy. Appendix G table G.2 and G.3 list the amount of secondary energy which can be produced from one *ton* of total biological yield in first transformation. Figure 4.2 shows this in a graph. The yield of secondary energy is between $3,2$ and $9,7$ $GJ\ HHV/DM\ ton$ for liquid biofuels. The production of other bioenergy yields lies between $2,2$ and $7,7$ $GJ\ HHV/DM\ ton$. These energy yields of secondary energy are lower than the energy content of primary energy.

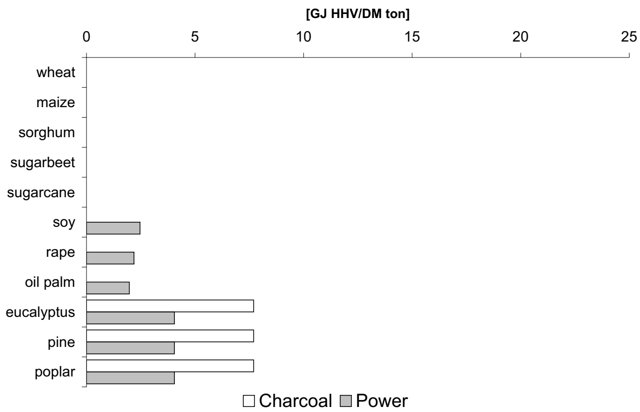
A below average amount of liquid biofuels are produced from sorghum, which has a low harvest index. An above average amount of liquid biofuels are produced from sugarbeet which has a high harvest index and a high fraction index. Besides sugarbeet, oil crops have in general also high yields of liquid biofuels. This is because the oil from oil crops, which is the main resource of biodiesel, has a high energy content ($37,7$ of fats vs $17,3$ $HHV/DM\ ton$ of starch). Secondly, oil crops produce valuable byproducts which are valued with the energy equivalent (e_{eq}). The oil from soy beans represents $1/3$ of the value while the press cake is $2/3$. Therefore, the energy equivalent for soy is twice the yield of biodiesel.

Oil from oil crops can also be used for power. Here, the energy equivalent is twice the yield of power. Figure 4.2(b) does not differentiate between power and the energy equivalent. The energy equivalent of oil crops is already included in the yield of power. Power produced from fuelwood gives twice the amount of power compared to oil crops. Charcoal produced from fuelwood yields twice as much as power.

Figure 4.2: Amount of secondary energy and energy equivalents (e_{eq}) which can be produced from the total biological yield in first transformation for seven crops and four trees



(a) Liquid biofuels

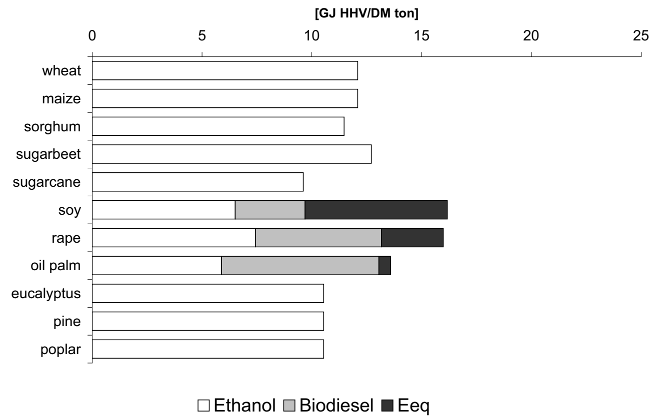


(b) Other bioenergy

Second transformation

Second transformation utilizes both the economic and the residue yield to produce liquid biofuels. Appendix G table G.4 lists the amount of secondary energy which can be produced from one *ton* of total biological yield. Figure 4.3 shows this in a graph. The yield of liquid biofuels lies between 9,6 and 16,1 $GJ\ HHV/DM\ ton$. Secondary energy yields less energy than the energy content of primary energy. But it yields more energy than first transformation.

Figure 4.3: Amount of secondary energy and energy equivalents (e_{eq}) which can be produced from the total biological yield in second transformation for seven crops and four trees



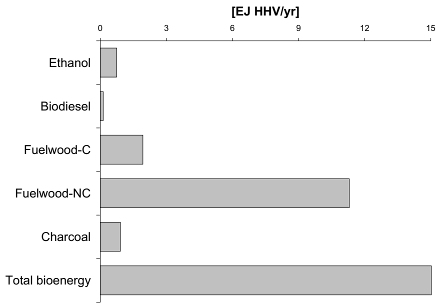
For sorghum, which has a large residue yield, second transformation is viable to produce 3,5 times the amount of liquid fuels per *ton* of total biological yield. For sugarbeet, second transformation produces only 1,6 times the amount of liquid fuels per *ton* of total biological yield. First generation conversion technologies cannot produce liquid biofuels from trees. Second generation conversion technologies are able to do so. However, the calculated yield is lower than the yield of (most) other crops.

Differences between crops become smaller for second generation. The difference between the crop which produces the least and the most liquid biofuels is in first transformation a factor 3,0. In second transformation this reduces to a factor 1,7.

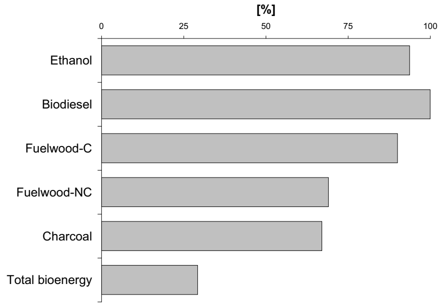
4.1.3 Consumption of bioenergy in 2005

Appendix G table G.5 to G.7 show the consumption of bioenergy and its feedstock per country. Figure 4.4 shows the covered bioenergy in this research. This research considers 50 countries and only several sources of bioenergy. Figure 4.4 (b) shows the fraction which the consumption of these 50 countries cover of global bioenergy consumption. Figure 4.4 (c) shows the consumption liquid biofuels and wood charcoal again on a smaller scale.

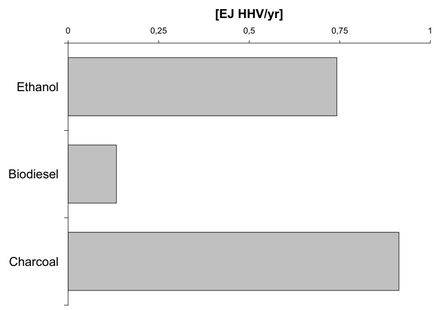
Figure 4.4: Covered global consumption of bioenergy in 2005; expressed by energy and the covered fraction



(a) energy



(b) covered fraction



(c) liquids and charcoal

Sources: [IEA, 2007], [FAO, 2007a], and [IEA, 2008]

Figure 4.4 (a,c) shows that energy consumption of ethanol ($0,74\ EJ\ HHV/yr$) is six times the consumption of biodiesel ($0,13\ EJ\ HHV/yr$). However both are much smaller than the energy consumption of coniferous fuelwood (fuelwood-C) and non-coniferous fuelwood (fuelwood-NC).

Figure 4.4 (b) shows that the countries cover more than 90% of the global ethanol and biodiesel consumption (94% and 100%). The covered consumption of wood charcoal is the least complete with a covered fraction of 67%. The covered fraction of total bioenergy[1] is relatively small (29%), because the research excludes multiple sources of bioenergy, such as vegetal and animal waste.

[1]Total bioenergy consumption consists of five sources of bioenergy: primary solid biomass, biogas [IEA, 2008], biogasoline, biodiesels, and other liquid biofuels [IEA, 2007].

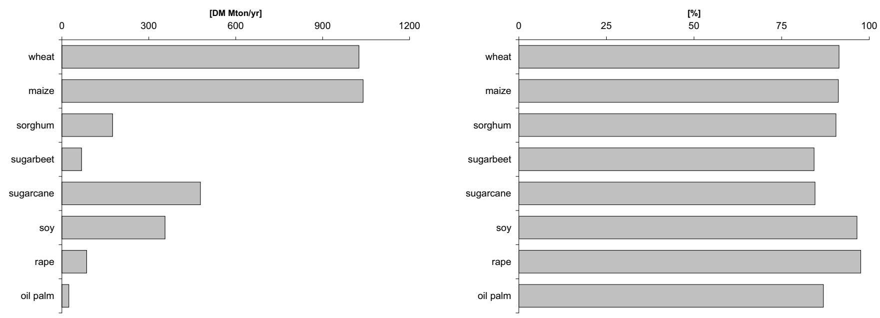
4.2 Agriculture results

4.2.1 Current system

Total biological yield

Appendix H tables H.1 and H.2 show the average annual production of the eight crops in the 50 countries over the period 1997-2001. Figure 4.5 shows the biomass production as total biological yield (10^6 $DM\ ton/yr$) and as a fraction of the global production.

Figure 4.5: Covered global average production of biomass in the period 1997-2001 for eight crops; expressed by total biological yield and by the covered fraction



(a) total biological yield (b) covered fraction

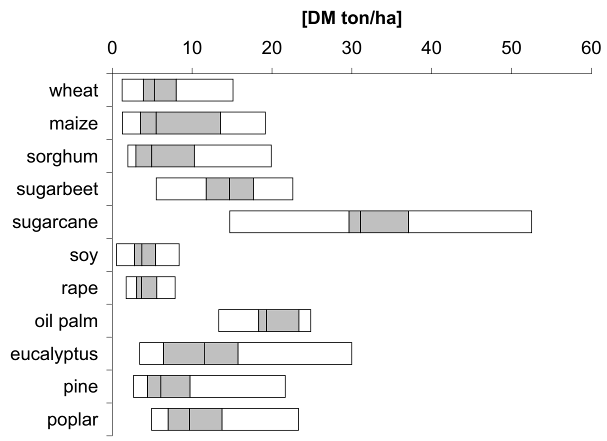
The first sub-figure shows that wheat and maize together represent the largest source of biomass of crop categories 1-3. Together these account for more biomass production than the other six crops combined. while the production of other crops such as sugarbeet, rape and oil palm are much smaller.

This research selected 50 countries in a way that 90% of the global production of crop categories 1-3 are covered. Therefore averaged results of this study are a good approximation of global averages. The second sub-figure shows the fractions of global production which is covered in this research. These fractions range from 84% of the global production of sugarbeet to 98% of the global production of rape. The covered fraction of sugarbeet, sugarcane, and oil palm are lower than the intended 90% of global production. For sugarbeet, this is because the calculation of the water use in Turkey gave results below the set limit. Sugarbeet production in Turkey accounts for 7% of the global production.

Appendix H tables H.3 to H.5 show the calculated dry total biological yield of eleven crops for 50 countries. Figure 4.6 shows the spread of the total biological yields in the database. The low end of a bar corresponds with the minimum value, the high end of the bar corresponds with the maximum value. The grey area corresponds to 50% of the yield values. The low end is the first quartile, the high end is the third quartile, and the middle is the median. The figure shows that total biological yields of crops lies between 0, 5 and 53 $DM\ ton/ha$.

The figure shows that sugarcane is the highest yielding crop of the perennial crops, while sugarbeet is the highest yielding crop of the annual crops. Oil crops

Figure 4.6: Spread of the total biological yield for seven crops and four trees; minimum, first, median, third quartile, maximum, and the interquartile range (grey)



and trees tend to have lower yields than other crops.

In the interquartile range, the difference between the first and third quartile, of maize is the largest with 10 $DM\ ton/ha$. However, the water footprint methodology multiplies the yield with other factors. Therefore, not the absolute difference is relevant, but the relative difference. This relative interquartile range ranges from a factor $1,3$ for sugarcane to a factor $3,9$ for maize.

Crop cultivation

Appendix H tables H.8 to H.9 list the capitals of 50 countries and their climate. When no data is available these serve as input for the location of crop cultivation of crop category 1-3 and serve in general as input for the location of crop category 4. Appendix H tables H.10 to H.24 list the location of crop category 1-3 per country, the climate and the start of the cultivation period. Figure 4.7 shows irrigation of cultivated land across the globe. Large irrigated areas are in China, India, Pakistan, and Egypt. Irrigation is negligible in South-America, Eastern Europe, and most of Africa.

Appendix H tables H.26 and H.27 show the calculated irrigated area fraction per crop. Figure 4.8 shows this spread of the irrigated area fraction per crop. This ranges from 0% for sugarbeet in Latvia to 94% for sugarbeet in Mexico. It shows minima for all crops of 0% and median values which are close to this value. Therefore, globally most crops are not irrigated. This corresponds with figure 4.7.

High maxima are observed for countries where crop cultivation only occurs in irrigated areas. Except for sugarbeet, the maximum irrigation values of wheat to sugarcane ($90 - 94\%$) correspond with crop cultivation in Egypt. Countries such as India and Pakistan have cultivation of crops both inside and outside the irrigated area. Calculation of the irrigation in these countries, therefore, gives values close to 50%. The first, median, and third quartile of soy, rape, and oil

Figure 4.7: Irrigation of permanent crop land

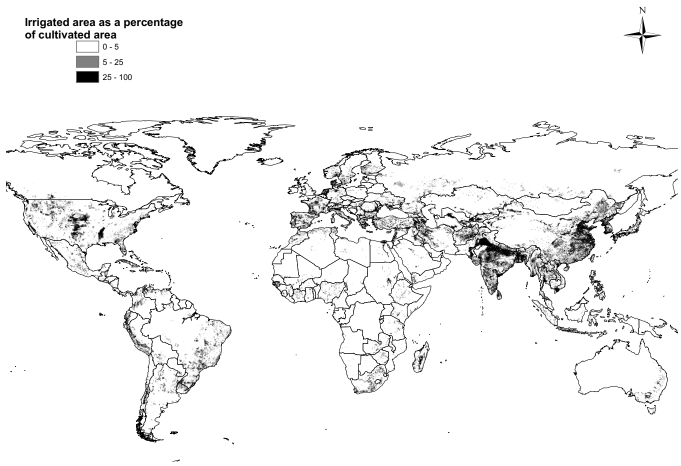
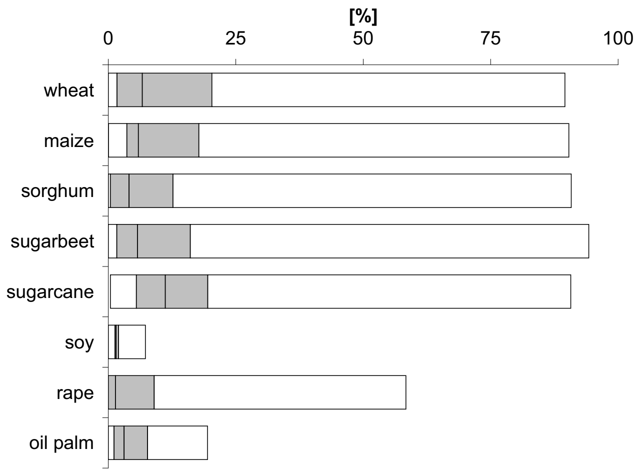


Figure 4.8: Spread of the fraction of irrigated crop land for eight crops; minimum, first, median, third quartile, maximum, and the interquartile range (grey)

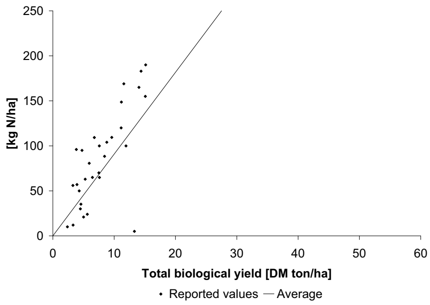


palm are lower than those of wheat and maize. Therefore, these crops have less irrigation than wheat and maize.

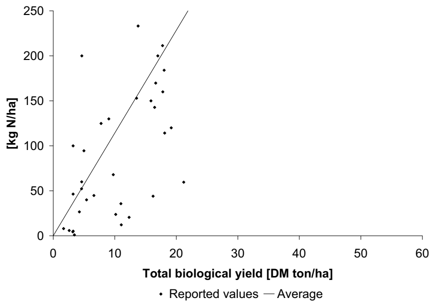
Appendix H tables H.28 to H.35 show the nitrogen application for eight crops in multiple countries. Figure 4.9 shows average nitrogen use for these crops versus their total biological yield. The average lines are average of the ratio between the average nitrogen use and the total biological yield. This is weighted with the production of each country. In case of wheat, India is the largest producer. This country uses a low amount of fertilizer per *ton* total biological yield. Therefore, the average line for wheat has a gentle slope.

The line of rape is with a slope of $24,4\ kg\ N/DM\ ton$ the steepest. Therefore the production of rape uses the largest amount of nitrogen. The crops sugarcane, oil palm and soy use the smallest amount of nitrogen ($1,9-3,8\ kg\ N/DM\ ton$). These average lines show a trend. Wheat, oil palm, and to a lesser extend sugarcane, all follow this trend closely. While the reported values of maize and sugarbeet show a large scatter.

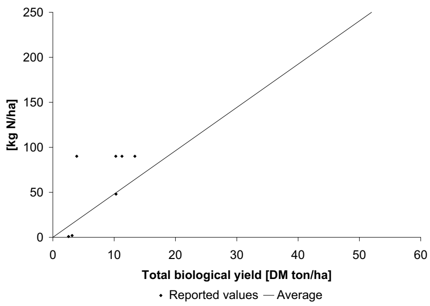
Figure 4.9: Nitrogen use for eight crops



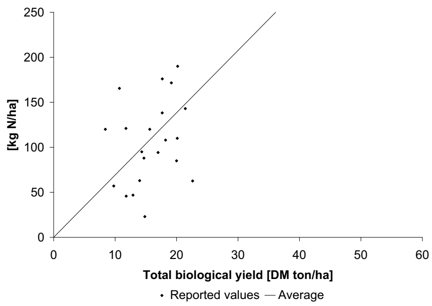
(a) Wheat



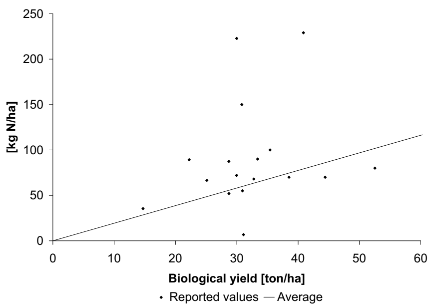
(b) Maize



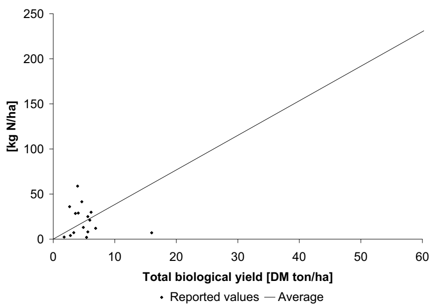
(c) Sorghum



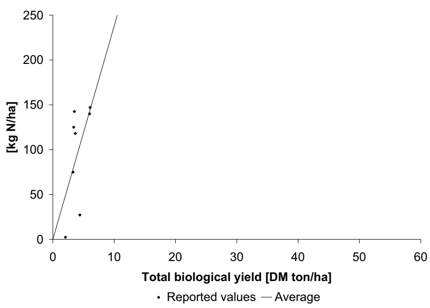
(d) Sugarbeet



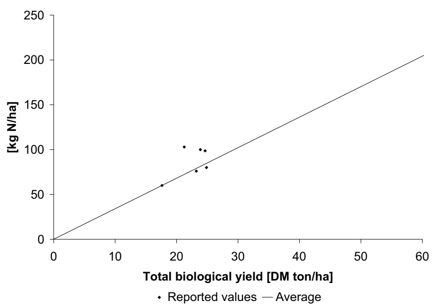
(e) Sugarcane



(f) Soy



(g) Rape



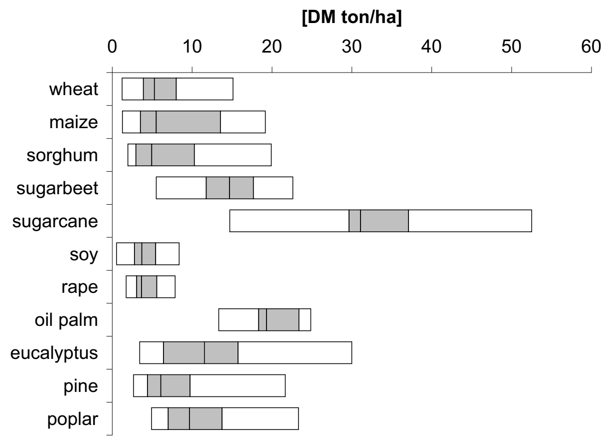
(h) Oil palm

4.2.2 HEI-system

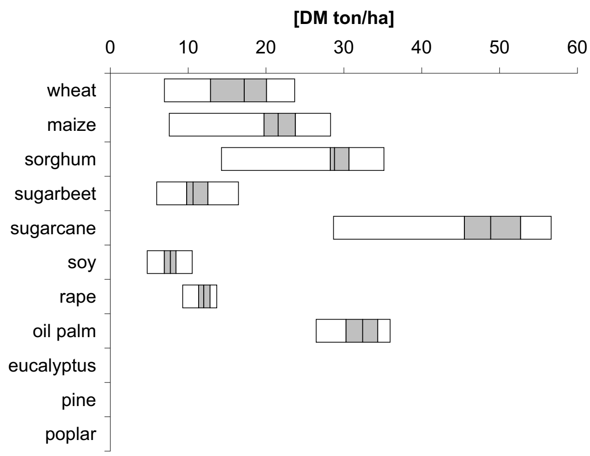
Total biological yield

Appendix H table H.6 and H.7 show the total biological yield per crop category 1-3 in the HEI-system. Figure 4.10 shows the spread of the total biological yields of the current situation and in the HEI-system. The total biological yield in the current system is between 0, 5 and 53 *DM ton/ha*. The total biological yield in the HEI-system is between 6, 0 and 57 *DM ton/ha*.

Figure 4.10: Spread of the total biological yield in the current and the HEI-system for seven crops and four trees; minimum, first, median, third quartile, maximum, and the interquartile range (grey)



(a) Current system



(b) HEI-system

The figure shows that almost all crops can increase their minimum, median, and maximum yields. This increase of the median total biological yield ranges from a factor 1,6 for sugarcane to a factor 5,8 for sorghum. The exception is sugarbeet. The median yield of this crop shows a decrease of a factor 1,4. Most likely cause of the low sugarbeet yields in the HEI-system is the deviating sugar content which the GAEZ uses. This is a factor 6 lower as the value in this study (8% vs 46%). However a correction with this factor does not bring sugarbeet yields into the expected range with other annuals. HEI yields for sugarbeets are therefore no basis for further conclusions. In both the current and the HEI-system, sugarcane is the most yielding perennial crop. In the current system, sugarbeet is the most yielding annual crop, while in the HEI-system this is sorghum.

The relative interquartile range is smaller in the HEI-system than in the current system. This is because the HEI- system has the same absolute spread, but these apply to higher yields. The relative interquartile range in the current system ranges from a factor 1,3 for sugarcane to a factor 3,9 for maize. In the HEI-system this ranges from a factor 1,1 for sorghum to a factor 1,6 for wheat.

Crop cultivation

The use of nitrogen in the HEI-system is based on the nitrogen per unit biomass of a country which achieves high yields. Table 4.1 shows these countries and the amount of nitrogen per unit biomass they use and the current global average.

Table 4.1: Fertilizer use in the current and HEI-system

Crop	current average fertilizer use *kg N/DM ton*	HEI fertilizer use *kg N/DM ton*
Wheat	9,1	10,3
Maize	11,4	2,8
Sorghum	4,8	6,7
Sugarbeet	6,9	5,5
Sugarcane	1,9	5,6
Soy	3,8	3,5
Rape	24,4	24,2
Oil palm	3,8	4

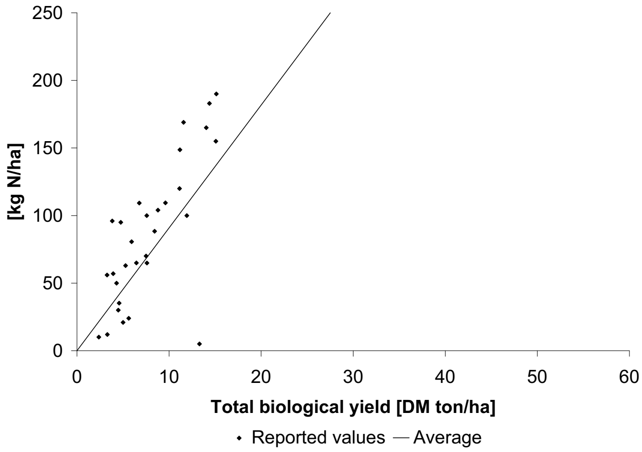
The table shows that, in most cases, the amount of nitrogen per *ton* of total biological yield is the same in both systems. For wheat the nitrogen use in the HEI-system becomes 10,3 *kg N/DM ton* which is close to the current average of 9,1 *kg N/DM ton*. Exceptions are maize and sugarcane. Maize cultivation in Belgium reports (very) high yields with a low fertilizer use. While sugarcane cultivation in Australia reports yields with high fertilizer use. The fertistat database reports the use of in-organic fertilizer, but not organic fertilizer, such as manure. These two countries deviate from the current average, most likely because they use a different amount of organic fertilizer.

4.3 Water results

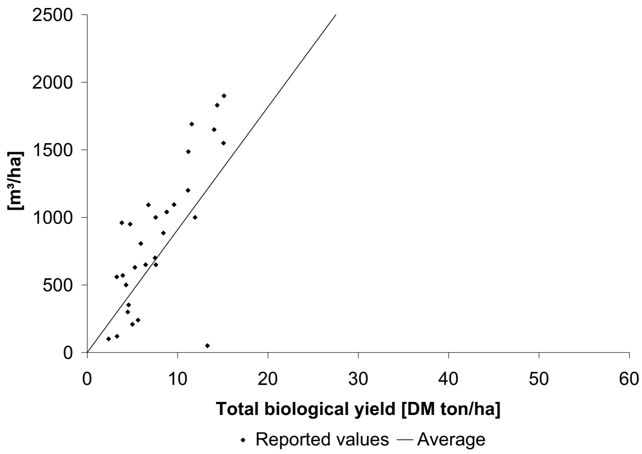
4.3.1 Current system

Water results consist of the three components: green, blue, and grey. Appendix I tables I.1 to I.19 show the green and blue crop water use. The grey component uses the fertilizer use. Figure 4.11 shows the fertilizer use and the grey component of crop water use (CWU_{grey}) for wheat. The figures have the same shape, except the units are different. This is because the calculation multiplies the nitrogen use only with several constants.

Figure 4.11: Fertilizer use and grey crop water use for wheat



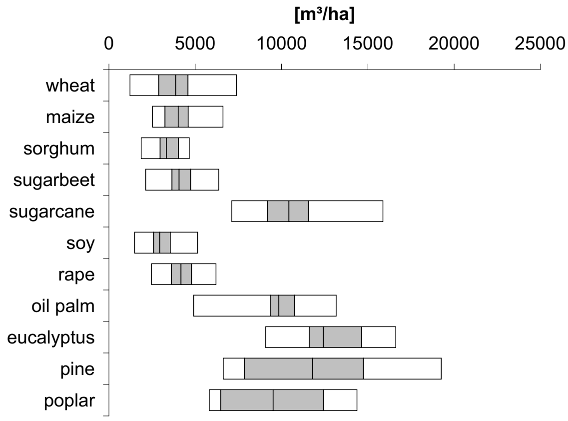
(a) nitrogen use



(b) crop water use - grey

Figure 4.12 shows the spread of crop water use per crop. Crop water use ranges from 1860 m^3/ha for wheat in Brazil to 19.260 m^3/ha for pine in Indonesia.

Figure 4.12: Spread of the crop water use in the current system for seven crops and four trees; minimum, first, median, third quartile, maximum, and the interquartile range (grey)



The figure shows that perennial crops consume more water than annual crops. This levels out the higher yields these perennial crops have due to a longer cultivation period. Of the annual crops sorghum and soy consume the less water during their cultivation. As these crops have lower first quartile, median and third quartile than other annuals. No perennial can be pointed out as being more water efficient than others due to the spread of results and differences in calculation method between crop categories 1-3 and trees.

Compared to the the total biological yield, the crop water use has a smaller spread. The relative interquartile range of the total biological yield ranges from a factor $1,3$ for sugarcane to $3,9$ for maize. While the relative interquartile range of crop water use ranges from a factor $1,2$ for sugarcane to $1,9$ for poplar. Therefore most of the variation in further parameters (virtual water content) is explained by variation in the total biological yield.

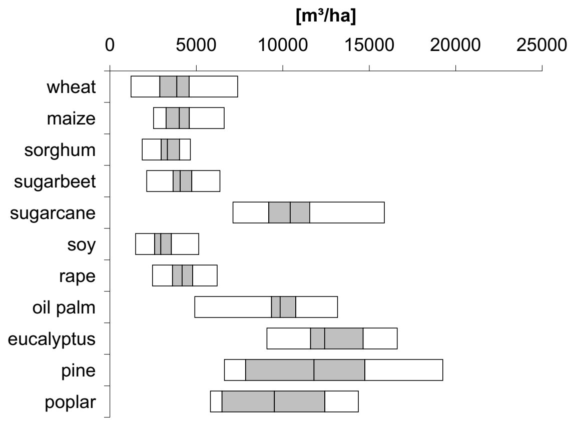
4.3.2 HEI-system

Figure 4.13 shows the spread of crop water use per crop for the current situation and the HEI-system. This ranges from 1600 m^3/ha for soy in Spain to 21000 m^3/ha for sugarcane in Tanzania.

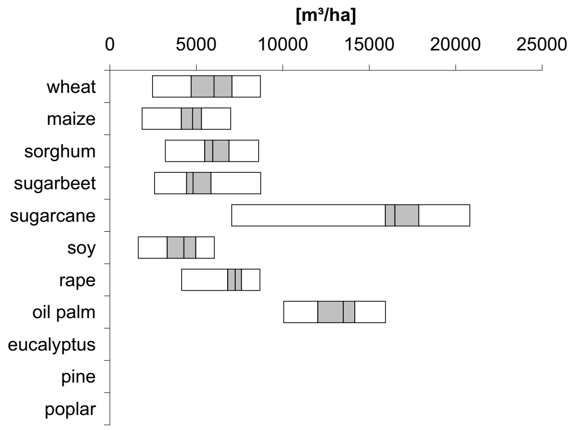
The crop water use increases for most crops in the HEI-system compared to the current system. This is because the HEI-system refers to irrigated yields. The water consumption of all crops which have an irrigation requirement larger than zero, which is not already satisfied by irrigation in the current situation, increases in the HEI-system. Exceptions to the general increase in crop water use are the minimum value of maize and sugarcane. Both exceptions are caused by the change in the grey component of the crop water use.

The relative interquartile range of the crop water use in the HEI-system ranges from a factor $1,1$ for rape to a factor $1,5$ for wheat. This is a similar

Figure 4.13: Spread of the crop water use in the current and HEI-system for seven crops and four trees; minimum, first, median, third quartile, maximum, and the interquartile range (grey)



(a) Current system



(b) HEI-system

range as the total biological yield in the HEI-system. Therefore variation in the virtual water content has to be explained by variation in both parameters.

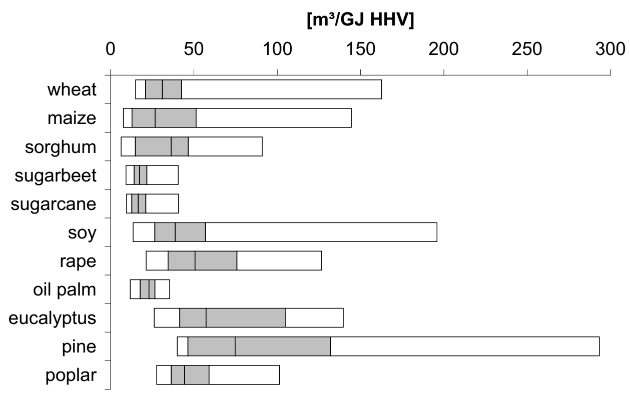
4.4 Water footprint of bioenergy results

4.4.1 Current virtual water content of bioenergy

Current system global scale

Appendix J table J.1 to J.19 show the virtual water content of primary energy produced from crops which are grown in the current system. Figure 4.14 shows the spread of this virtual water content. It shows that there is a large spread within the virtual water of each crop. Values vary between 6, 3 for sorghum in Spain and 293 $m^3/GJ\ HHV$ for pine in India.

Figure 4.14: Spread of the virtual water content of primary energy in the current system for seven crops and eight trees; minimum, first, median, third quartile, maximum, and the interquartile range (grey)



The virtual water content of primary energy is the result of combining the heating value of biomass, with the total biological yield, and the crop water use. Because the last two contain a spread in their values, the virtual water content also shows a large spread in it's values. The relative interquartile range ranges from a factor 1, 5 for sugarbeet to a factor 4, 0 for maize. The figure shows a pattern where for each crop the median is not in the middle between the minimum and the maximum value, these are skewed towards the minimum.

The high extremes of the virtual water content are best explained by a (very) low total biological yield. For example the high extreme of the virtual water content of primary energy is soy from Poland. A high extreme is caused either by low total biological yields or a high crop water use. Soy cultivation in Poland does not have a high crop water use, the crop water use is with a value of 2200 m^3/ha a factor 1, 3 lower than the median. However, the high virtual water content is caused by the low yields. Poland reports an average total biological yield of 0, 5 $DM\ ton/ha$ which is 7 times lower than the median.

This extreme value has several questionable aspects. First, soy from Poland represents less than 0, 1% of the global soy production in the period 1997-2001. Second, the climate in Warshaw is sub-continental temperate, while soy grows best in the tropics and sub-tropics [Fischer et al., 2000].

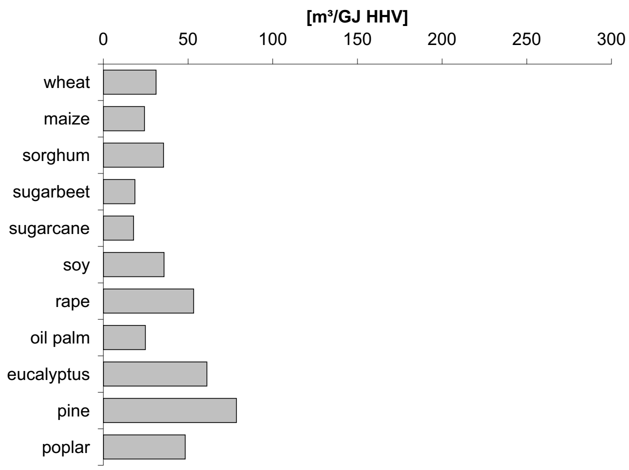
The low extremes are explained by both a high yield and a low crop water use. An example of a low extreme of the virtual water content of primary energy is sorghum from Spain. A low extreme is caused either by a high total biological yield or a low crop water use. The total biological yield here is 15 $DM\ ton/ha$, this is 3 times higher than the median value. The crop water use is 1900 m^3/ha, this is $1,8$ times lower than the median.

This extreme also has several questionable aspects. First, sorghum from Spain represents less than $0,1\%$ of the global sorghum production in the period 1997-2001. Second, the crop water use corresponds with sorghum cultivation in Madrid during the (cold) winter. This is unlikely as sorghum grows best in the (hot) tropics [Fischer et al., 2000].

The crop cultivation of sorghum in Madrid during the winter is chosen because section 3.3.3 sets two conditions for crop cultivation: 1) the temperature should be above 5 ^oC, 2) the precipitation should be at least half the potential evapotranspiration. For Madrid, these conditions are only met during the winter. Therefore the current crop water use is based on the best available data, but still likely to be erroneous. However, the largest influence on it's low virtual water content is not the low crop water use, but the high yield.

Most of the causes of the extremes can be explained by yield data. However they do contain questionable aspects and they represent only a small fraction of the global production. Therefore a better analysis is not based on these extremes, but uses global averages/medians. Figure 4.15 shows the weighted average of the virtual water content of primary energy for each crop. Values are weighted with the national production in the period 1997-2001. This average can be interpreted from a static and dynamic perspective. The first perspective describes the virtual water content of an average crop which is now on the world market. The second perspective describes what the virtual water content would be if one additional crop is produced in an average fashion.

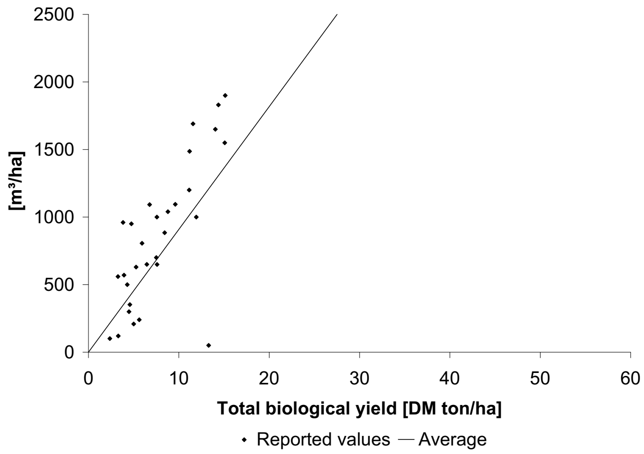
Figure 4.15: Average of the virtual water content of primary energy of crop categories 1-3 and median of the virtual water content of primary energy of crop category 4 in the current system



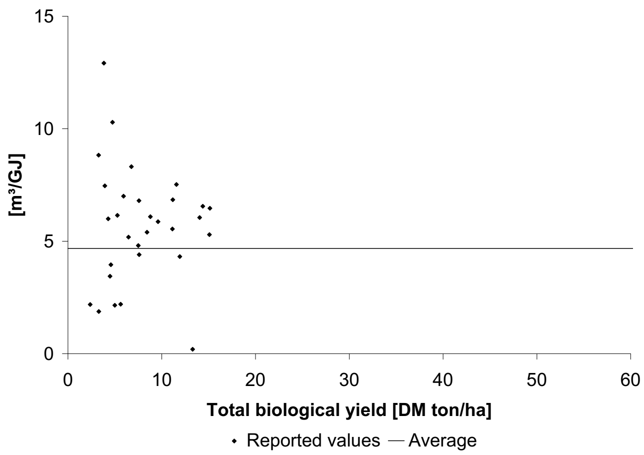
For trees, no figures on national production are known. Therefore the figure shows median values for trees. Both the average and median have similar values. In case of wheat, its average virtual water content of primary energy is $31,1\ m^3/GJ\ HHV$ and its median value is $31,5\ m^3/GJ\ HHV$.

The figure shows that these averages/medians range from 18 $m^3/GJ\ HHV$ for sugarbeet to 79 $m^3/GJ\ HHV$ for pine. Both sugarcrops and oil palm are the most water efficient sources of primary energy. The least efficient sources are rape and the three trees. Main cause is not the difference in energy content or crop water use, but the large difference in the total biological yield. For example the median yield of sugarcane is 31 $DM\ ton/ha$ which is 5 times the median yield of pine (6 $DM\ ton/ha$).

Figure 4.16: Grey crop water use and the virtual grey water content of primary energy of wheat



(a) crop water use - grey



(b) virtual water content - grey

The virtual water content is split into it's green, blue, and grey component. This grey component depends on the grey crop water use (m^3/ha) and the amount of primary energy which is obtained from one unit area. Figure 4.16 shows the grey crop water use and the grey component of the virtual water content of primary energy of wheat.

The choice for an fixed ratio between nitrogen use and biomass results in a fixed ratio between grey crop water use and biomass. This on itself results in a constant grey water content. In the first figure the average line corresponds with a steepness of 91 $m^3/DM\ ton$. Because one *ton* of wheat has an energy content of 19,4 $GJ\ HHV/DM\ ton$, this corresponds with 4,7 $m^3/GJ\ HHV$. This is the average line in the second figure.

Tables 4.2 to 4.5 show the calculation of the green, blue, and grey component of the virtual water content of primary energy from eleven crops. The first table shows general information on crop cultivation. The second table calculates the green and blue crop water use from the crop water requirement and irrigation requirement. The third table calculates the grey crop water use from nitrogen use and the total biological yield. The last table calculates the virtual water content of primary energy from the three kinds of crop water use, total biological yield and the energy content of biomass. The tables list the calculation for countries which have a large production share or give median values for the virtual water content.

These countries have values of the virtual water content which are close to the weighted average. For example wheat from Canada has a virtual water content of 35 m^3/GJ, the global average deviates by only 10% (31 m^3/GJ). However, there are also exceptions. Sorghum from the United States has a virtual water content of 17 m^3/GJ, while the global average is a factor two higher (36 m^3/GJ). More differences on national scales are discussed in the section 4.4.1.

Table 4.2: General information on crop cultivation for eleven crops

Crop	country	latitude	longitude	start cultivation day nr.	cultivation period (LGP) *days*
Wheat[a]	Canada	52,6	-106,8	135 (May)	180
Maize[a]	United States	41,9	-93,9	105 (Apr)	150
Sorghum[a]	United States	37,9	-97,4	105 (Apr)	130
Sugarbeet[a]	France	50,1	2,4	105 (Apr)	180
Sugarcane[a]	Brazil	-27,4	151	1 (Jan)	365
Soy[a]	United States	33,9	-84,4	135 (May)	150
Rape[a]	Germany	53,8	11,4	105 (Apr)	180
Oil palm[b]	Malaysia	3,2	102	1 (Jan)	365
Eucalyptus	Brazil	-15,5	-47,5	1 (Jan)	365
Pine	United Kingdom	51,3	-0,1	1 (Jan)	365
Poplar	Netherlands	52,2	4,5	1 (Jan)	365

a) Source: [USDA, 1994]
b) Source: [Leff et al., 2004]

Table 4.3: Calculation of green and blue crop water use for eleven crops

Crop	crop water requirement $\sum CWR$ $mm/period$	effective precipitation $\sum P_{effective}$ $mm/period$	irrigation requirement $\sum IR$ $mm/period$	irrigated area f_{iA} $-$	green crop water use CWU_{green} m^3/ha	blue crop water use CWU_{blue} m^3/ha
Wheat	500	239	261	1,0%	2390	27
Maize	606	398	208	5,9%	3980	123
Sorghum	638	332	306	12,4%	3320	378
Sugarbeet	420	292	128	11,1%	2920	142
Sugarcane	1340	968	374	6,4%	9680	238
Soy	571	387	184	1,3%	3870	25
Rape	428	289	139	3,9%	2890	54
Oil palm	1220	1220	0	2,8%	12180	0
Eucalyptus	1320	1320	-	-	13240	-
Pine	652	652	-	-	6520	-
Poplar	511	511	-	-	5110	-

Table 4.4: Calculation of grey water use for eleven crops

Crop	nitrogen application rate $N_{rate}{}^{a}$ $kg\ N/ha$	fertilizer area f_{fA} $-$	a $kg\ N/DM\ ton$	total biological yield Y_{total} $DM\ ton/ha$	average nitrogen use N_{use} $kg\ N/ha$	grey crop water use CWU_{grey} m^3/ha
Wheat	50	100%	11,6	4,3	50	500
Maize	150	100%[a]	9,4	15,9	150	1500
Sorghum	100	90%[a]	6,7	13,4	90	900
Sugarbeet	145	43%	2,8	22,6	62,6	626
Sugarcane	55	100%	1,8	30,9	55	550
Soy	30	70%[a]	3,5	5,9	21	210
Rape	-	-	24,4	7,9	193	1930
Oil palm	-	-	4	24,6	98,6	986
Eucalyptus	-	-	7,5	30,0	225	2250
Pine	-	-	7,5	6,0	45	450
Poplar	-	-	7,5	9,3	70	700

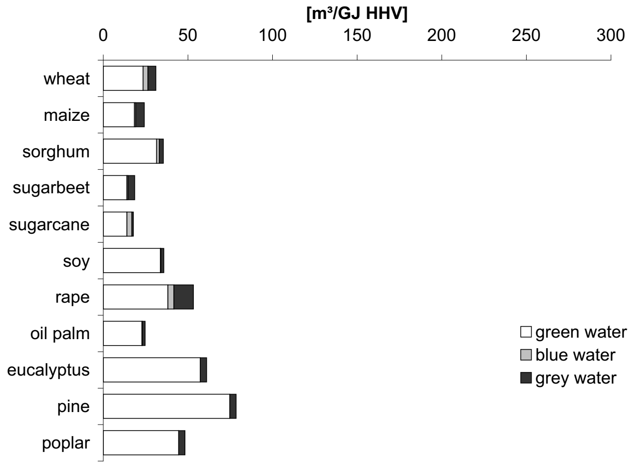
a) source: [FAO, 2007b]

Table 4.5: Calculation of the virtual water content of primary energy for eleven crops

Crop	green crop water use CWU_{green} m^3/ha	blue crop water use CWU_{blue} m^3/ha	grey crop water use CWU_{grey} m^3/ha	total biological yield Y_{total} $DM\ ton/ha$	energy content of biomass $e_{biomass}$ $GJ\ HHV/DM\ ton$	virtual water content v_{total} $m^3/GJ\ HHV$
Wheat	2390	27	500	4,3	19,4	35
Maize	3980	123	1500	15,9	19,9	17,7
Sorghum	3320	378	900	13,4	19,9	17,3
Sugarbeet	2920	142	626	22,6	17,4	9,4
Sugarcane	9680	238	550	30,9	19,6	17,2
Soy	3870	25	210	5,9	21,1	32,8
Rape	2890	54	1930	7,9	21,1	29,2
Oil palm	12180	0	986	24,6	21,6	24,7
Eucalyptus	13240	0	2250	30,0	19,7	26,2
Pine	6520	0	450	6,0	19,7	58,9
Poplar	5110	0	700	9,3	19,7	31,6

Figure 4.17 is similar to figure 4.15 but with a break-down into it's green, blue and grey virtual water content. The figure shows that green water makes up for the largest part of the virtual water content. The share of blue and grey water is considerably smaller. The largest fraction of blue water is observed for wheat, sugarcane, and rape. India has a large production share of these three crops and cultivates these in it's irrigated area.

Figure 4.17: Green, blue, and grey virtual water for the average of the virtual water content of primary energy of crop categories 1-3 and the median of the virtual water content of primary energy of crop category 4 in the current system.



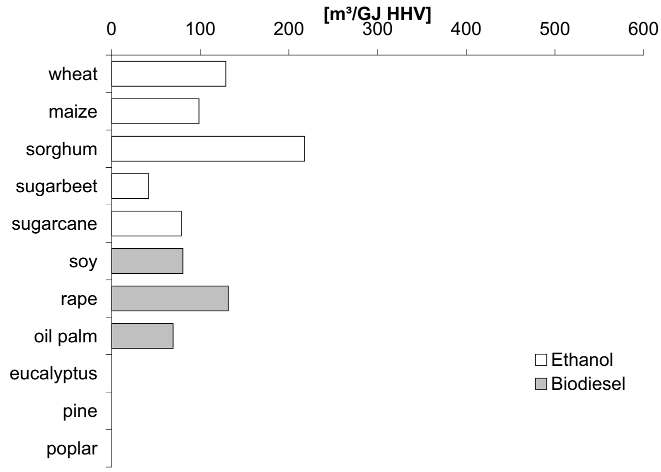
In absolute terms rape has with $11,6\ m^3/GJ\ HHV$ the largest virtual grey water content. In relative terms the virtual grey water content of maize, sugarbeet, and rape are equally large and make up for a share of 21% of the total virtual water content. In relative terms sugarcane, soy, and pine have the smallest grey water content with a share of 5%.

Appendix J tables J.20 to J.23 show the virtual water content of secondary energy in the current situation produced with first transformation. Figure 4.18 shows the virtual water content of secondary energy based on the values presented in figure 4.15.

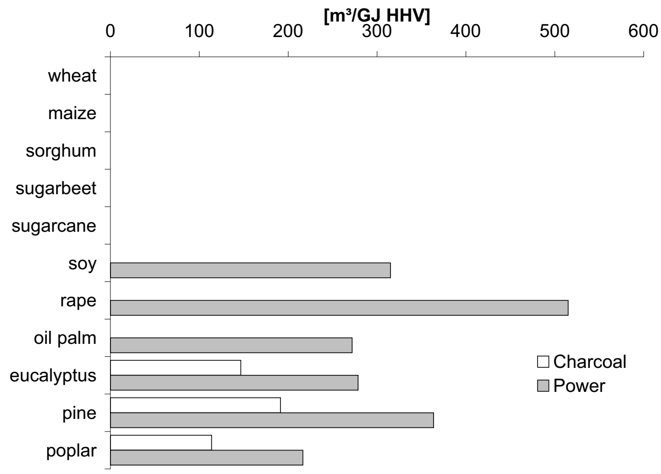
Similar to the average of primary energy this average of secondary energy can be interpreted from a static and dynamic perspective. The first perspective describes the virtual water content of secondary energy which is produced from an average crop which is now on the world market. The second perspective describes what the virtual water content of secondary energy would be if one additional crop is produced in an average fashion. The values in figure 4.18, therefore, do not correspond to the average virtual water content of secondary energy, but to the virtual water content of secondary energy if it would be produced from 'average' biomass.

Both sub-figures show the virtual water content of secondary energy. This is $2-11$ times higher than the virtual water content of primary energy. The virtual water content of primary energy ranges from 18 for sugarbeet to 79 $m^3/GJ\ HHV$ for pine. The virtual water content of secondary energy ranges from 42 for

Figure 4.18: Average of the virtual water content of secondary energy of crop categories 1-3 and the median of the virtual water content of secondary energy of crop category 4 of the current system in first transformation



(a) Liquid biofuels



(b) Other energy

ethanol from sugarbeet to 515 $m^3/GJ\ HHV$ for power from rape (oil).

The first sub-figure shows the liquid biofuels ethanol and biodiesel. The virtual water content of these biofuels varies in a large amount per crop. Therefore it cannot be concluded that in general one fuel is more water efficient than the other. This is illustrated by the fact that both the most water efficient and most water inefficient biofuel both concern ethanol. Sugarbeet is on average the most water efficient crop for liquid biofuels being twice as water efficient as liquid biofuels from sugarcane or oil palm (42 versus 80 or 72 $m^3/GJ\ HHV$). On average, sorghum is the least water efficient crop for liquid biofuels.

The fact that sorghum is the least water efficient source of liquid biofuels is contrary to what figure 4.12 on the crop water use suggests. This figure shows that per unit area sorghum consumes less water than sugarbeet or any of the other cereals. That sorghum is the least water efficient source of liquid biofuels has two main causes. First is the amount of ethanol which can be produced from one $DM\ ton$ of biological yield. From one $DM\ ton$ of sorghum 3 GJ of ethanol can be produced, while from one $DM\ ton$ sugarbeet 8 GJ of ethanol can be produced. Second is the large difference in the total biological yield. The median yield of sorghum is $4,9$ $DM\ ton/ha$, while sugarbeet yields 15 $DM\ ton/ha$.

Charcoal is twice as water efficient as power. This is because twice as much charcoal is produced from one unit of wood as power. Further is power from oil (crops) less water efficient than power from wood. In the figure power from the most water efficient tree (poplar) has a virtual water content of 220 $m^3/GJ\ HHV$. Power from the most water efficient oil crop (oil palm) requires $1,3$ times as much water (280 $m^3/GJ\ HHV$). This pattern repeats itself for the least water efficient sources (pine and rape). Therefore, power from oil of oil crops is less water efficient than power from wood.

The virtual water content is listed as $m^3/GJ\ HHV$. Consumers might be more interested in the volume of water which is involved per unit consumption or delivered service. Table 4.6 shows the average global virtual water content of four energy services. Here 'travel by car' is based on biodiesel from soy and ethanol from sugarcane. Next part shows that these global values are close to the national value of ethanol from sugarcane in Brazil, but also to liquid biofuels in other countries. The 'barbecue' is based on the median of eucalyptus charcoal as it's water efficiency is between charcoal from pine and poplar. The 'computer use' is based on power from palm oil. This because Malaysian palm oil has been used for power generation in the Netherlands [Blok et al., 2007]. Further is the global average virtual water content of palm oil close to the value of Malaysia.

Table 4.6: Average/median virtual water content of four commonly used energy services

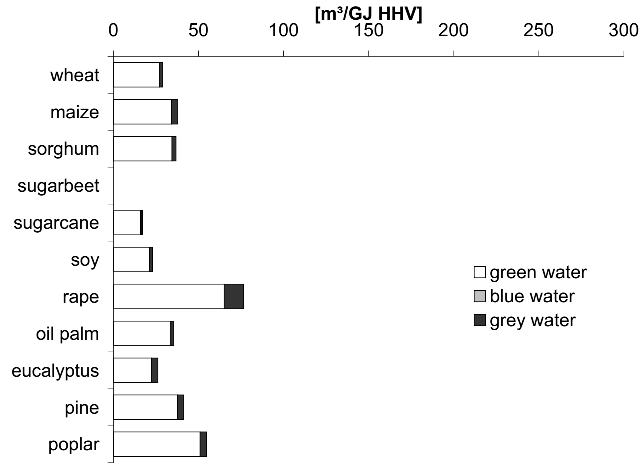
Energy service	origin	virtual water content	virtual water content
Travel by car (diesel[a])	soy biodiesel	$80,6\ m^3/GJ\ HHV$	$200\ liter/km$
Travel by car (gasoline[b])	sugarcane ethanol	$78,7\ m^3/GJ\ HHV$	$290\ liter/km$
Barbecue for a family of four[c]	eucalyptus charcoal	$110\ m^3/GJ\ HHV$	$5200\ liter/family$
Computer use[d]	power from palm oil	$290\ m^3/GJ\ HHV$	$640\ liter/hour$

a) The consumption is $2,5 * 10^{-3}\ GJ\ HHV/km$. This is based on the assumption that a car which uses biodiesel has the same energy efficiency as a car which uses diesel. The fuel economy of cars is given in miles per gallon. These are based on two test cases, one which is comparable to a city, the other is comparable to a highway. This research uses the average of the two. Base consumption is $32 - 42\ mpg$ ($16\ km/l$), this corresponds with a Volkswagen Golf 4 *cyl*, $1,9\ L$, Manual $5 - spd$, Diesel [DOE, 2008]. Gas/diesel oils have a density of $0,844\ kg/liter$ and higher heating value of $45,66\ GJ/ton$ [IEA, 2005].
b) The consumption is $3,7 * 10^{-3}\ GJ\ HHV/km$. This is based on the assumption that a car which uses ethanol has the same energy efficiency as a car which uses gasoline. Base consumption is $21 - 28\ mpg$ ($10\ km/l$), this corresponds with a Volkswagen Golf 4 *cyl*, $2\ L$, Manual $5 - spd$, Regular [DOE, 2008].
c) The consumption is $47 * 10^{-3}\ GJ\ HHV$. This is based on the use of $1,5\ kg$ of wood charcoal.
d) The consumption is $2,2 * 10^{-3}\ GJ\ HHV/hour$. This is based on an energy consumption of $600\ W$.

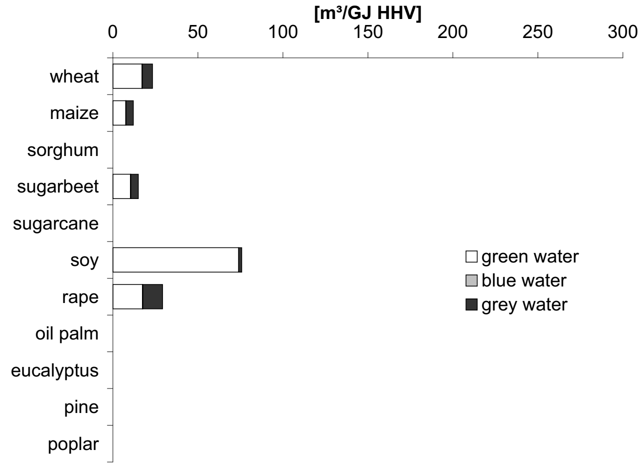
Current system national scale

The previous part described water consumption of bioenergy in general. This part focuses on four countries: Brazil, Germany, India, and the United States. Brazil and the United States are the largest producers of ethanol, while Germany is the largest producer of biodiesel [Dufey, 2006] [IEA, 2007]. The United States uses a large amount of fertilizer, while India uses a small amount. For irrigation the inverse is true.

Figure 4.19: Virtual water content of primary energy in the current system of Brazil and Germany



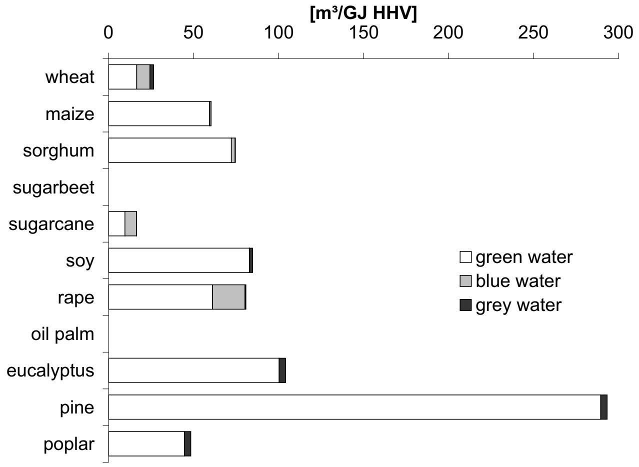
(a) Brazil



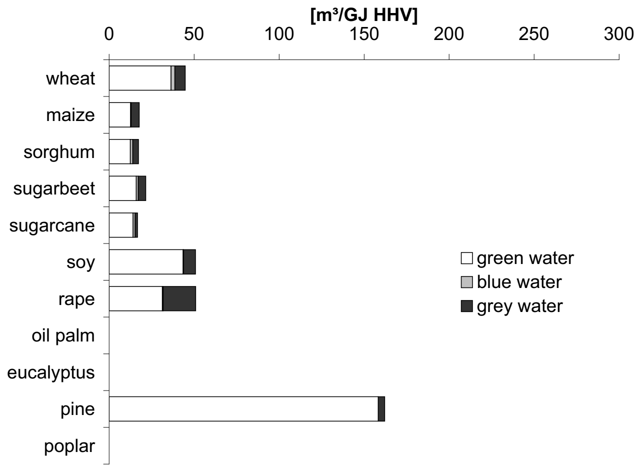
(b) Germany

Figures 4.19 and 4.20 show the virtual water content of primary energy in these countries. These values can also be interpreted from a static and dynamic perspective. The first perspective describes the virtual water content of an average crop which is now produced in a specific country. The second perspective describes what the virtual water content would be if one additional crop is produced in a specific country in an average fashion.

Figure 4.20: Virtual water content of primary energy in the current system of India and the United States



(a) India



(b) United States

Values of the virtual water content of primary energy range from 12 for maize in Germany to 293 $m^3/GJ\ HHV$ for pine in India. Figure 4.17 showed the average virtual water content of primary energy. Here sugarcrops and oil palm are to most water efficient sources of primary energy, while rape and trees are the least water efficient. This trend presents itself again in some amount. Sugarcane is the most water efficient crop in Brazil, India, and the United States, while pine is the least efficient crop in India and the United States.

On a national scale, there are also deviations from the global pattern. Rape in Brazil and India consumes twice as much water per unit bioenergy compared to wheat. While in Germany and the United States these crops are produced equally water efficient. Further in Germany and the United States maize is more water efficient than wheat, in Brazil and India this is the other way around.

Besides differences in the ranking there are also absolute differences. Rape has a virtual water content of 81 $m^3/GJ\ HHV$ in India, but only 29 $m^3/GJ\ HHV$ in Germany. Both countries have a large share in the production of rape (17% and 10% in the period 1997-2001 [FAO, 2007a]). Therefore there is a large spread in the virtual water content which cannot be attributed to outliers.

Besides differences in the total volume of virtual water which is used to produce on unit of primary energy, also differences exist in its composition. Sugarcane cultivation in India and the United States has in both cases a virtual water content of 17 $m^3/GJ\ HHV$, in both cases green water makes up the largest part of the virtual water content. However, in India a large volume is supplied by blue water (7 $m^3/GJ\ HHV$), while in the United States this is negligible (1 $m^3/GJ\ HHV$). The virtual grey water content of sugarcane in the United States is $1,4$ $m^3/GJ\ HHV$, this content is in India at least ten times lower ($0,1$ $m^3/GJ\ HHV$).

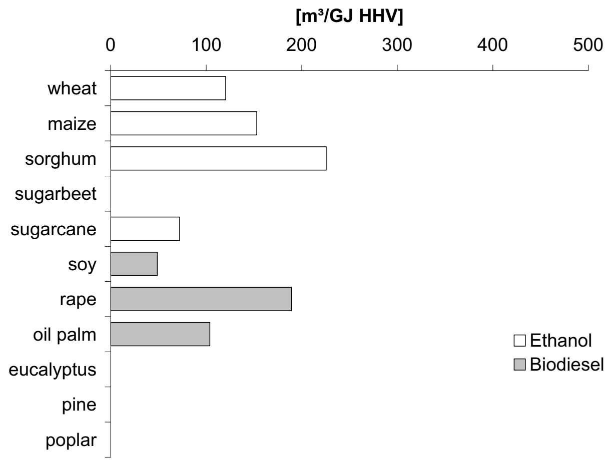
There is a large difference between the global average and national values. For describing the current situation, therefore, the national values are much better than the global average. This corresponds with the static perspective. However, for describing a change in production, which is the dynamic perspective, national values are less solid. These only hold if the additional crop is produced in a specific country in the average fashion. An example in which it does not hold is an exporting country which uses additional crops for bioenergy and reduces it's export by the same amount. In this case the additional crop is either not produced at all, or is produced anywhere except for the exporting country.

A sideways observation based on the colors is the relation between the total virtual water content and the grey component. A high fertilizer use corresponds with a high grey component, and intuitive it would be logical to state that this increases the total virtual water content. However the figure shows several cases which are an exception to this. The fertistat database reports fertilizer use both for wheat and maize in India. The figure shows that the grey component of wheat is larger than the grey component of maize. However, primary energy of wheat is twice as water efficient as maize (27 vs 60 $m^3/GJ\ HHV$).

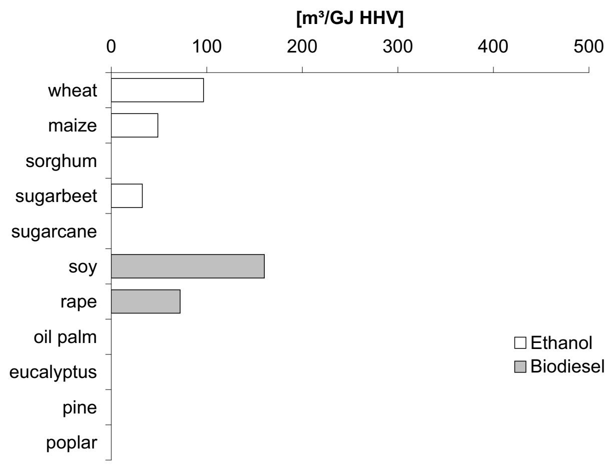
Other pairs of a country with a low fertilizer use and a high fertilizer use which are reported in the fertistat database are: wheat cultivation in both Brazil and India, rape cultivation in both India and the United States, wheat cultivation in the United States and Germany. In these cases the country which uses a high amount of fertilizer (kg N/ha) has a lower total virtual water content than the country which uses a low amount of fertilizer. Therefore it can be concluded that fertilizer use does not increase the virtual water content, but in several cases causes a lower virtual water content. The increase in fertilizer use in these cases corresponds with an increase in the total biological yield. This causes an increase in the green and blue water use efficiency. This increase is larger than the increase in water consumption due to the extra fertilizer.

Figures 4.21 and Figures 4.22 show the virtual water content of ethanol and biodiesel produced of crops cultivated in each of the four countries. Values of the virtual water content of secondary energy produced with first transformation in

Figure 4.21: Virtual water content of secondary energy in the current system of Brazil and Germany



(a) Brazil

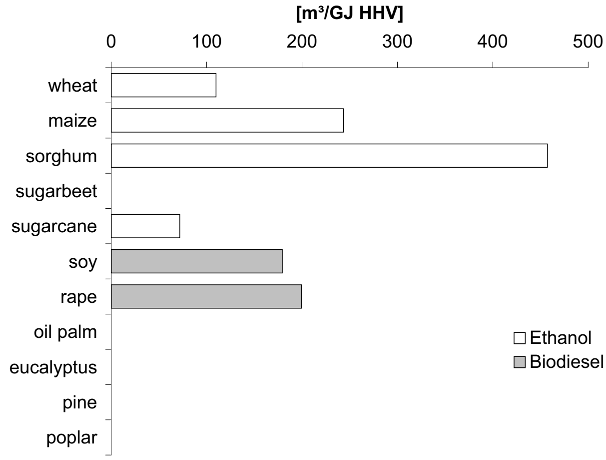


(b) Germany

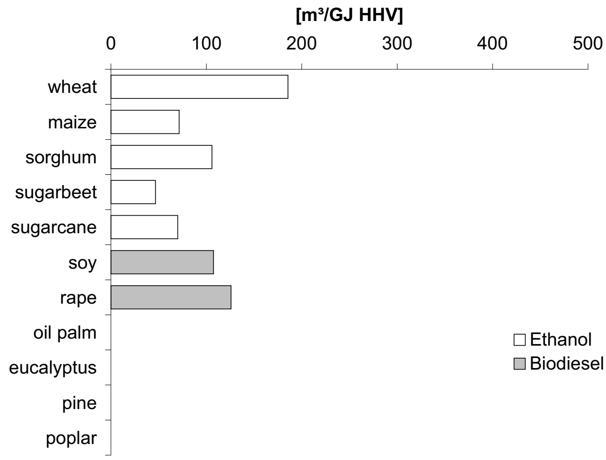
these four countries ranges from 33 for ethanol from sugarbeet in Germany to 457 $m^3/GJ\ HHV$ for ethanol from sorghum in India.

Crops which are currently used as a source for liquid biofuels are one of the most water efficient crops. In Brazil and India, most of the liquid biofuels are produced from sugarcane, in Germany from rape, and in the United States from maize [Dufey, 2006]. Liquid biofuels from these crops all have the same virtual water content of 72 $m^3/GJ\ HHV$. Brazil, India, and the United States together have a share of 95% of the global ethanol consumption (47%, 0, 6%, and 47%) [IEA, 2007]. Germany on itself has a share of 62% of the biodiesels consumption [IEA, 2007]. Therefore, the average virtual water content of all liquid biofuels is close to the value of 72 $m^3/GJ\ HHV$.

Figure 4.22: Virtual water content of secondary energy in the current system of India and the United States



(a) India



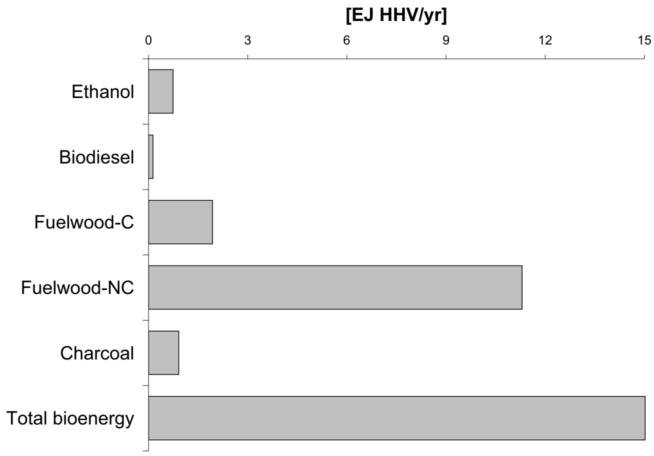
(b) United States

Further almost all countries have an alternative crop for liquid biofuels which is equally or more water efficient than the crop which is currently used. In the United States ethanol from sugarbeet or sugarcane are both alternatives for ethanol from maize. Ethanol from both sources is more water efficient than ethanol from maize (47 or 70 $m^3/GJ\ HHV$ versus 72 $m^3/GJ\ HHV$). In the same way biodiesel from soy is more water efficient than ethanol from sugarcane in Brazil (49 versus 72 $m^3/GJ\ HHV$), or ethanol from sugarbeets is more water efficient than biodiesel from rape in Germany (33 versus 72 $m^3/GJ\ HHV$).

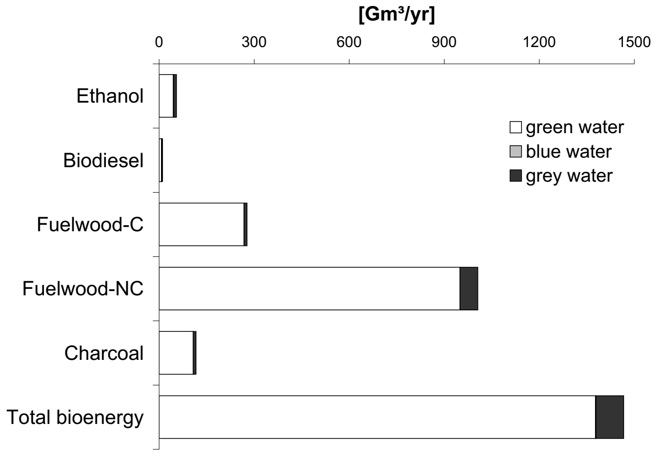
4.4.2 Water footprint of bioenergy consumption in 2005

Appendix G tables G.5 to G.7 list the consumption volume of bioenergy and the selected feedstock. Figure 4.23 shows the consumption of bioenergy expressed both by energy and by its water footprint. The bioenergy covered in this research is 15 $EJ\ HHV/yr$, this corresponds with a water footprint of 1467 Gm^3/yr.

Figure 4.23: Global bioenergy consumption and the water footprint of global bioenergy consumption



(a) energy consumption



(b) water footprint

Sources: [IEA, 2007], [FAO, 2007a], and [IEA, 2008]

The total water footprint of bioenergy consumption is 1467 Gm^3/yr, of this liquid biofuels make up for 66 Gm^3/yr. The consumption and water footprint of liquid biofuels consist for the main part of ethanol (55 Gm^3/yr) and for a smaller part of biodiesel (11 Gm^3/yr). This research covered almost all ethanol and biodiesel consumption. An extrapolation of this water footprint to the global consumption gives a water footprint of liquid biofuels of 70 Gm^3/yr. For the largest part the water footprint consists of green water. Besides green water also grey water makes up for a significant part (16% for ethanol, 31% for biodiesel).

The global water footprint is 7450 Gm^3/yr [Hoekstra and Chapagain, 2007]. Compared to this figure the water footprint of liquid biofuels is quite small ($< 1\%$). The volume of water which is associated with liquid biofuels is comparable with the global consumption of potatoes [Chapagain and Hoekstra, 2004]. The water footprint of liquid biofuels corresponds with an energy consumption of $0,9$ $EJ\ HHV/yr$. On average, the virtual water content of liquid biofuels is therefore 73 $m^3/GJ\ HHV$. This is close to the value(s) found for ethanol from Brazil, India, and the United States, or for biodiesel from Germany.

Fossil fuels are consumed by the transport sector, these fuels can be replaced by liquid biofuels. The transport sector in 2005 consumed globally 95 $EJ\ HHV$[2] of liquid fuels. The water footprint of these (average) liquid biofuels which replace these fossil fuels is 6950 Gm^3/yr. If only liquid biofuels supply the global transport sector then the global water footprint doubles.

Wood fuels make up for the largest part of the water footprint of bioenergy consumption (1400 Gm^3/yr). This consists for the largest part on non-coniferous fuelwood (Fuelwood-NC, 1000 Gm^3/yr), the second largest part is coniferous fuelwood (Fuelwood-C, 280 Gm^3/yr). Compared to liquid biofuels the wood fuels cover a smaller portion of the global consumption. By using simple extrapolation, an estimation is made of the global water footprint of wood fuel consumption. This is for an energy consumption of 20 $EJ\ HHV/yr$ a global water footprint of wood fuel consumption of 1940 Gm^3/yr.

Compared to the global water footprint, this is a large amount (26%). This volume of water is comparable to the volume of water which associates with the global consumption of maize and rice combined [Chapagain and Hoekstra, 2004]. The water footprint of coniferous and non-coniferous fuelwood corresponds with an combined energy consumption of 13 $EJ\ HHV/yr$. On average the virtual water content of fuelwood is therefore 97 $m^3/GJ\ HHV$.

Coal can be replaced by fuelwood. The global consumption of coal in 2005 was 121 $EJ\ HHV$[3] [IEA, 2008]. If this is replaced by (average) fuelwood, then its water footprint is 11.700 Gm^3/yr. If only fuelwood supplies the current demand for coal, the global water footprint doubles or triples.

Interpretation of the water footprint of wood fuel consumption deviates from other water footprints. The volume of water which is used by forests is much higher than the volume of water which is used by cropland (40.000 versus 6700 Gm^3/yr) [Rockstrom and Gordon, 2001]. The water footprint corresponds with the volume of water which is attributed to the service these forests deliver. In case of the water footprint of fuel wood consumption this is only a small fraction (5%). The other 95% corresponds with other services/functions which these forests possess. Therefore a breakdown into different colors of virtual water does not make sense.

[2] This is based on the global consumption of petroleum products by the transport sector. The source reports energy consumption of 87 $EJ\ LHV$ [IEA, 2008], this is increased by 10% to convert LHV into HHV.

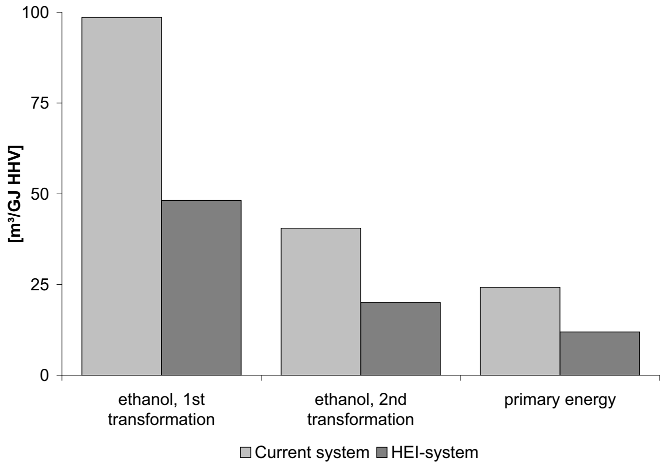
[3] The source reports energy consumption in LHV, this is not increased to convert LHV into HHV.

The water footprint methodology does not include wood as a product. With the results on fuelwood an extrapolation can be made to cover all wood products. The water footprint of 1400 Gm^3/yr corresponds with a wood volume of $1,5$ Gm^3/yr. The global roundwood consumption in 2005 was $3,6$ Gm^3/yr [FAO, 2007a]. The global water footprint of wood consumption is therefore 3300 Gm^3/yr. This gives a global water footprint, including wood consumption, of 11.000 Gm^3/yr.

4.4.3 Water savings of the optimal system on the virtual water content of bioenergy

In the optimal system bioenergy is produced differently from the current system. This implies a change in biomass production, where globally biomass is produced in a HEI-system. It also contains a change in the amount of liquid biofuels which is produced from biomass. Further, it contains a combination of these two factors. Both factors improve the efficiency in which resources are used. The virtual water content of bioenergy in these cases is lower. Figure 4.24 shows the impact of the optimal system on the virtual water content of bioenergy regarding the global average of maize.

Figure 4.24: Average water consumption of bioenergy from maize



The figure presents three ways of biomass use. The first is as primary energy, which includes the whole crop. The second way is as secondary energy which is produced with first generation conversion technology/in first transformation. This covers only the utilization of a small part of the biomass. The third way is as secondary energy which is produced with second generation conversion technology/in second transformation. This covers a larger fraction of the biomass than first generation, but still less than the whole crop. These three ways are applied to two production systems: the current system and the HEI-system.

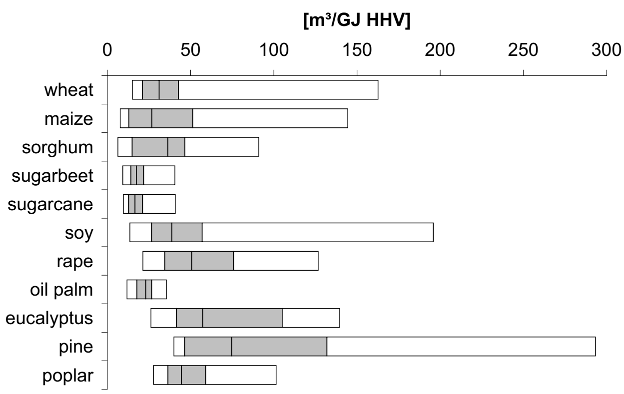
The figure shows that in the current system secondary energy in first transformation has the largest virtual water content. Compared to this secondary energy produced in second transformation is twice as water efficient. While compared to this primary energy is again twice as efficient.

The figure also shows that primary energy in the HEI-system is twice as water efficient in the current system. The water footprint is a linear system. Therefore this increase in water efficiency also shows itself for secondary energy produced in first and second transformation. The next parts describe the effects of the HEI-system and second transformation on the virtual water content of bioenergy into more detail.

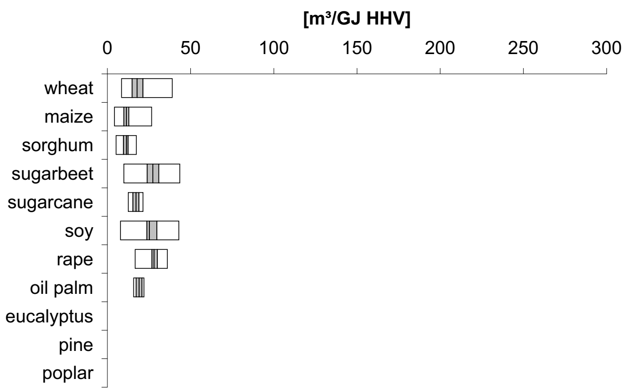
HEI-system global scale

Appendix G tables J.24 to J.39 list the virtual water content of primary energy of crops produced in the HEI-system. Figure 4.25 shows the spread of these results and sets these against the spread of primary energy which is currently produced. Values of the virtual water content of primary energy which is produced in the current system ranges from 6, 3 for sorghum in Spain and 293 $m^3/GJ\ HHV$ for pine in India. When trees are excluded, the range is to 196 $m^3/GJ\ HHV$ for soy in Poland. The range in the HEI-system is from 4, 3 for maize in Chile to 43 $m^3/GJ\ HHV$ for soy in Guatemala (or 44 $m^3/GJ\ HHV$ for sugarbeet in Latvia).

Figure 4.25: Spread of the virtual water content of primary energy of seven crops and four trees in the current and HEI-system; minimum, first, median, third quartile, maximum, and the interquartile range (grey)



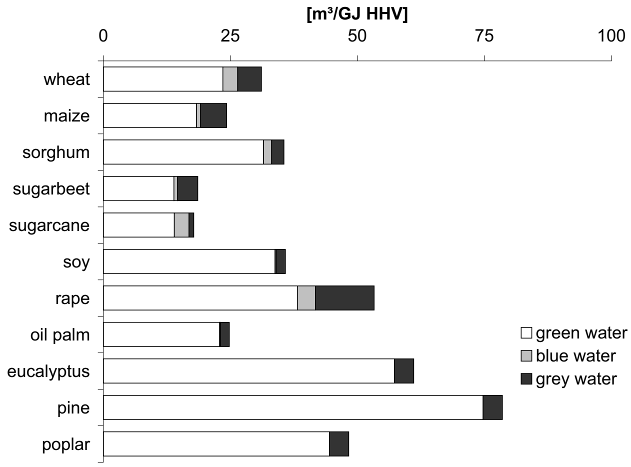
(a) current system



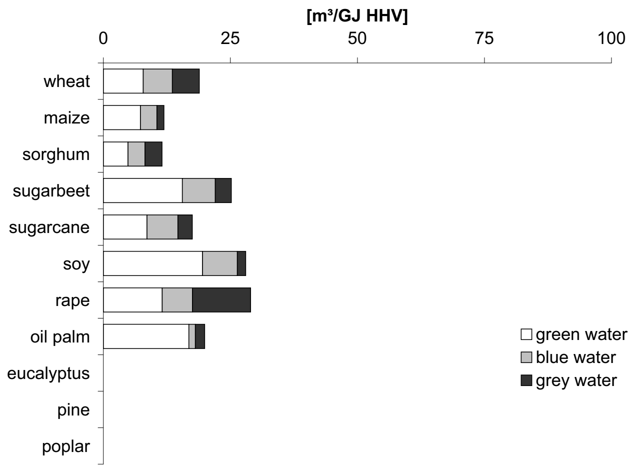
(b) HEI-system

The figure shows that the spread in the virtual water content of primary energy of most crops becomes considerably smaller. The largest change is that high extremes in the HEI-system are much lower than those in the current system. Besides the extremes, the quartiles are less spread out also. In the current system, the relative interquartile range of the virtual water content ranges from a factor $1,5$ for sugarbeet to a factor $4,0$ for maize. In the HEI-system, the relative interquartile range ranges from a factor $1,1$ for rape to a factor $1,4$ for wheat. Most of this decrease in spread is caused by changes in the total biological yield.

Figure 4.26: Average of the virtual water content of primary energy of crop categories 1-3 and the median of the virtual water content of primary energy of crop category 4 in the current and HEI-system



(a) Current system



(b) HEI-system

Figure 4.26 shows the weighted average of virtual water content of primary energy produced in the current system and in the HEI-system. Values of the virtual water content of primary energy which is produced in the current system ranges from 18 for sugarbeet and 79 $m^3/GJ\ HHV$ for pine. When trees are excluded the range is to 53 $m^3/GJ\ HHV$ for rape. The range in the HEI-system is from 12 for sorghum to 29 $m^3/GJ\ HHV$ for rape.

All crops, with the exception of sugarbeet, are on average more water efficient in the HEI-system than in the current system. Therefore, the HEI-system is more water efficient than the current situation. The HEI-system produces on average sugarcane a factor $1,03$ more water efficient and on average sorghum a factor 3 more water efficient.

The current and HEI-system show similar rankings in water efficiency. In both the current system and in the HEI-system, maize is on average more water efficient than wheat. Also oil palm is more water efficient than rape or soy. An exception is sorghum. This crop shows a large increase in water efficiency and goes from the least to the most water efficient cereal.

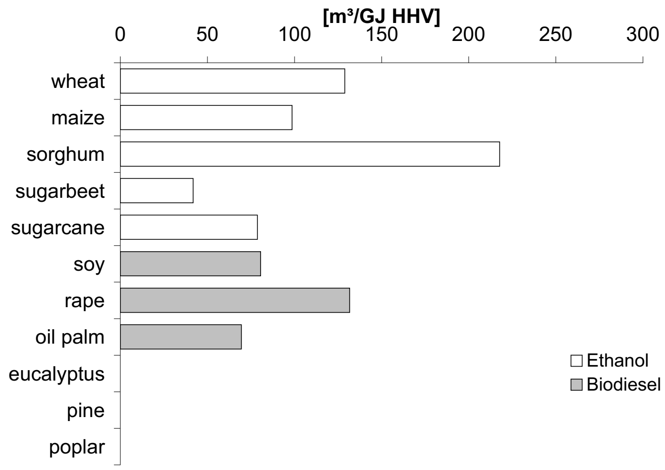
The composition of the color of the virtual water content changes in the HEI-system. In the current system, green water is the dominant part of virtual water of wheat, while on average blue water plays a minor role. The HEI-system contains the same amount of precipitation per unit area and therefore the same green crop water use. However, it assumes that all yields are irrigated which means that the volume and share of blue water of wheat increases from 10% to to 29%. Other crops also show an increase in their share of blue water.

The HEI-system uses a high amount of fertilizer per unit area. Compared to the current system this is about the same amount of fertilizer per unit wheat. Therefore in absolute terms the grey component remains the same size. The HEI-system further contains less yield reducing factors, which result in a higher efficiency of green and blue water. Therefore the share of grey water of wheat doubles from 16% to 30%. Other crops show a similar increase in their share of grey water.

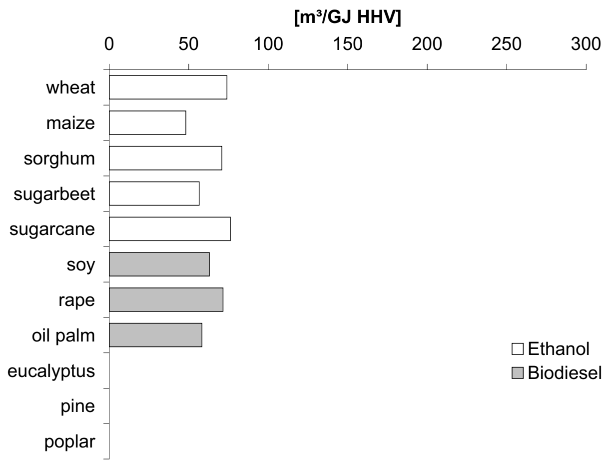
Appendix G tables J.40 and J.41 list the virtual water content of secondary energy produced in the HEI-system. Figure 4.27 shows this virtual water content and the virtual water content of secondary energy which is produced in the current system. In the current system values of the virtual water content of secondary energy ranges between 72 for biodiesel from oil palm (or 42 for ethanol from sugarbeet) to 220 $m^3/GJ\ HHV$ for ethanol from sorghum. In the HEI-system the virtual water content ranges from 48 for ethanol from maize to 76 $m^3/GJ\ HHV$ for ethanol from sugarcane.

The virtual water content of primary and of secondary energy are related. Therefore, both primary and secondary energy become more water efficient in the HEI-system. Large changes in the water efficiency are observed for both sorghum and rape. As a result differences between biofuels from various crops are minimal.

Figure 4.27: Average of the virtual water content of secondary energy of crop categories 1-3 in the current and HEI-system in first transformation



(a) current system

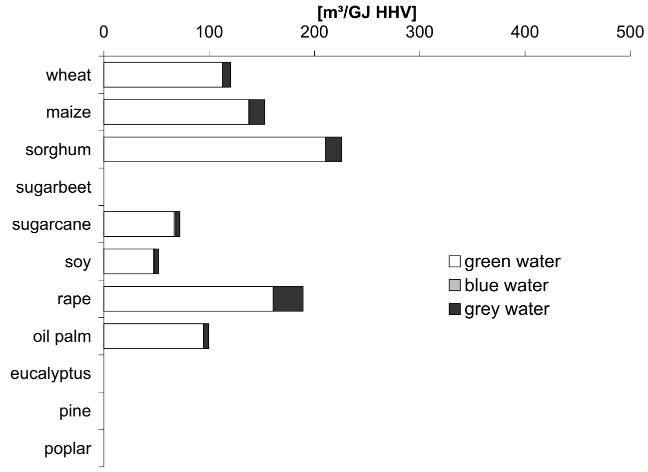


(b) HEI-system

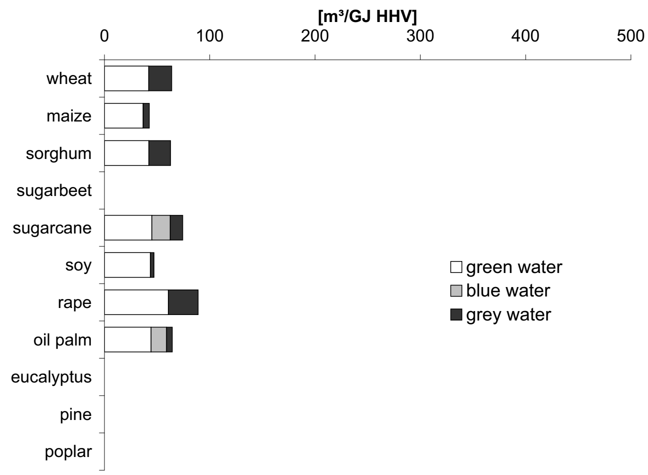
HEI-system national scale

Figures 4.28 and 4.29 show the virtual water content of liquid biofuels produced in the current and HEI-system for Brazil and India. Liquid biofuels produced from starch and sugarcrops refer to ethanol, liquid biofuels from oil crops refer to biodiesel.

Figure 4.28: Virtual water content of liquid biofuels in the current and HEI-system in Brazil in first transformation



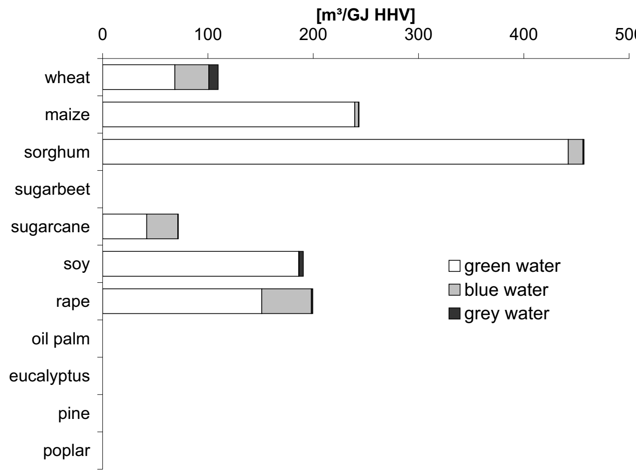
(a) Brazil - current



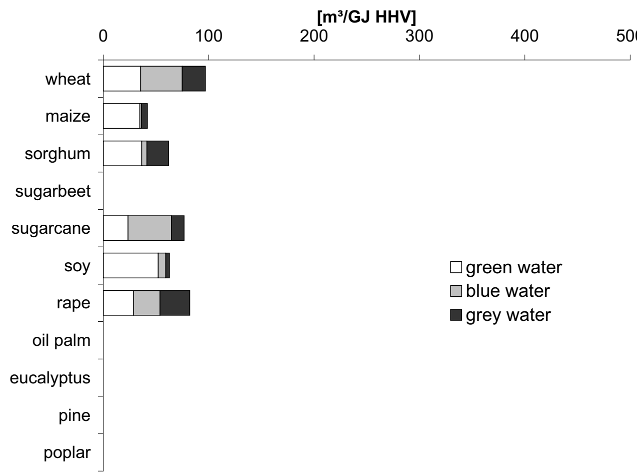
(b) Brazil - HEI

In the HEI-system on a global scale differences between liquid biofuels from various crops are minimal. The figures show that the differences between liquid biofuels from the various crops in Brazil and India diminish. Also the differences between these countries becomes minimal. For example ethanol from sugarcane in Brazil has a virtual water content of 74 and from India this is

Figure 4.29: Virtual water content of liquid biofuels in the current and HEI-system in India in first transformation



(a) India - current



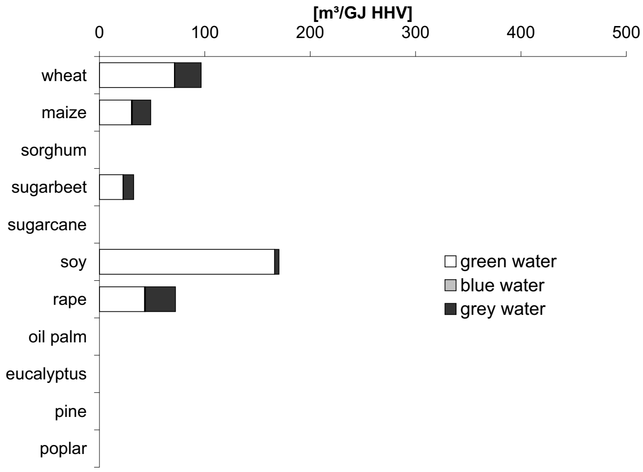
(b) India - HEI

77 $m^3/GJ\ HHV$.

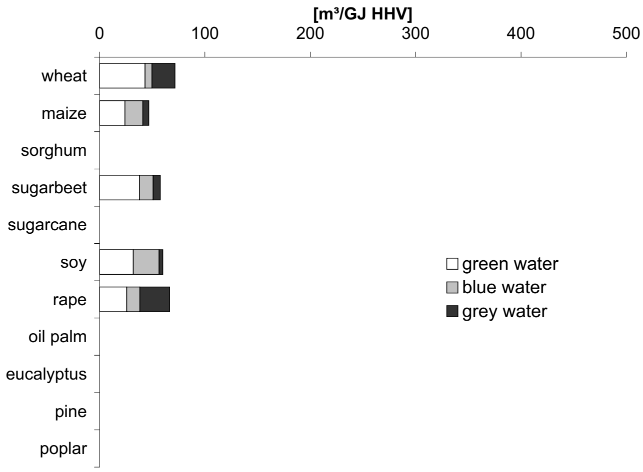
The figure shows that the ethanol from wheat is produced twice as water efficient in the HEI-system in Brazil compared to the current system in Brazil (64 versus 120 $m^3/GJ\ HHV$). Sorghum is produced three times more water efficient in the HEI-system. The HEI-system shows for India also large increases in the water efficiency for crops such as sorghum and rape. The virtual water content of the HEI-system shows for both countries a decrease of the volume and share of green water and an increase for the blue and grey water content. This pattern is similar to the changes of the global average.

Figure 4.30 and 4.31 are similar to the previous figures, but show the water consumption of liquid biofuels for Germany and the United States. Similar

Figure 4.30: Virtual water content of secondary energy in the current and HEI-system in Germany in first transformation



(a) Germany - current

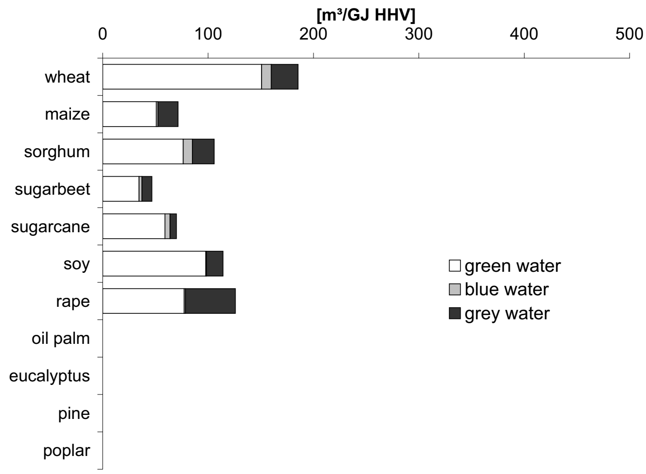


(b) Germany - HEI

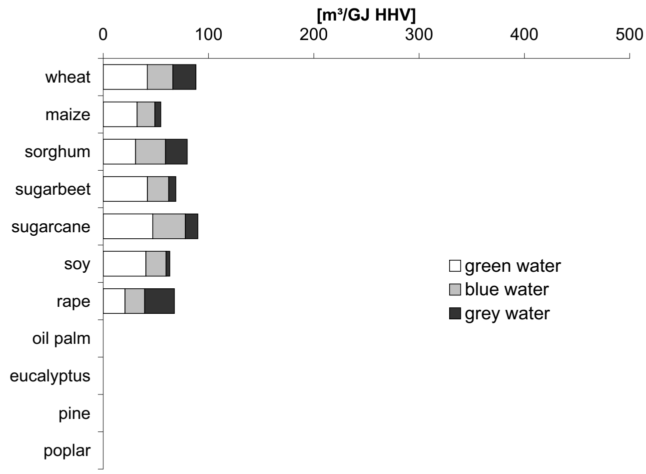
to the previous figures the HEI-system shows a higher water efficiency. The virtual water content of ethanol from wheat in Germany decreases from 97 to 72 $m^3/GJ\ HHV$. ethanol from maize which is both in Germany and the United States already produced water efficient shows a smaller increase in water efficiency. For maize in Germany this is from 49 to 47 $m^3/GJ\ HHV$ and for the United States from 72 to 55 $m^3/GJ\ HHV$.

The current main source of biodiesel in Germany is rape, and the current main source of ethanol in the United States is maize. The current and HEI-system in Germany show a small difference in the virtual water content of biodiesel, here the HEI-system is 7% more water efficient (72 versus 67 $m^3/GJ\ HHV$). The HEI-system in the United States results in a larger improvement of the wa-

Figure 4.31: Virtual water content of secondary energy in the current and HEI-system in the United States in first transformation



(a) United States - current



(b) United States - HEI

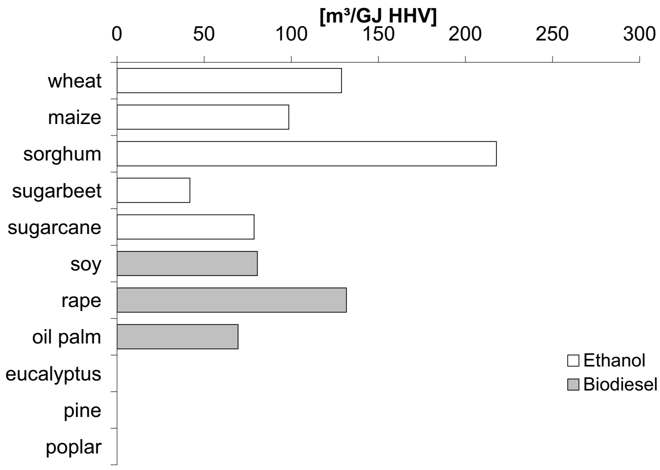
ter efficiency of ethanol (from 72 to 55 $m^3/GJ\ HHV$).

The HEI-system does increase the water efficiency of crops. This effect is larger for crops which are produced water inefficient than crops which are already produced water efficient. Crops which are currently the main feedstock for liquid biofuels belong to the latter category. Therefore the volume of water, which is required for the production of liquid biofuels, cannot be reduced, or only be reduced by a small amount by increasing the amount of external input in the agricultural system.

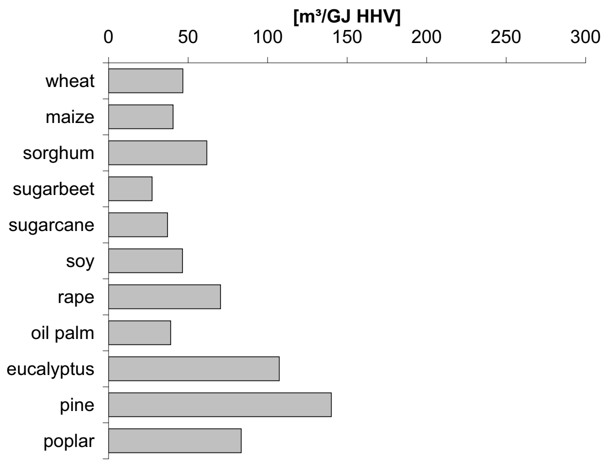
Second transformation

Appendix G tables J.42 to J.46 show the virtual water content of liquid biofuels produced with second transformation. Figure 4.32 shows the virtual water content of liquid biofuels produced from average crops cultivated in the current system. Here liquid biofuels of starchcrops, sugarcrops, and trees refer to ethanol. For oilcrops, it refers to a mixture of biodiesel and ethanol. The virtual water content of liquid biofuels in first transformation ranges from 42 for ethanol from sugarbeet to 220 $m^3/GJ\ HHV$ for ethanol from sorghum. In second transformation this ranges from 27 for ethanol from sugarbeet to 140 $m^3/GJ\ HHV$ for ethanol from pine.

Figure 4.32: Average of the virtual water content of secondary energy of crop categories 1-3 and the median of the virtual water content of secondary energy of crop category 4 in the current system in first and second transformation



(a) First transformation



(b) Second transformation

Second transformation produces from sugarbeet 1,6 times more liquid biofuels from one *ton* of total biological yield and from sorghum $3,5$ times. The virtual water content of liquid biofuels changes therefore by this amount. In first transformation ethanol from maize has a virtual water content of 99 $m^3/GJ\ HHV$ while in second transformation it has a virtual water content of 41 $m^3/GJ\ HHV$.

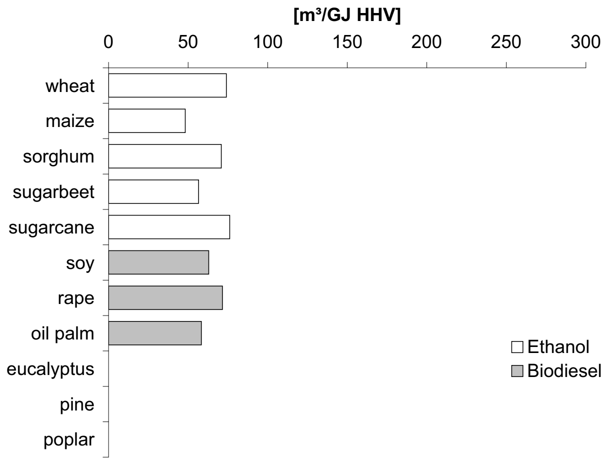
In first transformation the most water efficient sources of liquid biofuels are sugarbeet, sugarcane, and oil palm. In second transformation these are still the most water efficient crops. Ethanol from sorghum shows a large increase in its water efficiency, but it remains the least water efficient crop of the cereals. Second transformation is viable to also produce liquid biofuels from trees. Ethanol from eucalyptus has a virtual water content of 107 $m^3/GJ\ HHV$. This is comparable with ethanol from maize, but produced with first transformation. Ethanol produced from trees is in second transformation the least water efficient source of liquid biofuels.

Figure 4.33 shows the virtual water content of liquid biofuels produced from average crops cultivated in the HEI-system. Liquid biofuels of starchcrops, sugarcrops, and trees refers to ethanol. Liquid biofuels of oilcrops refer to a mixture of biodiesel and ethanol. The virtual water content of liquid biofuels in first transformation ranges from 48 for ethanol from maize to 76 $m^3/GJ\ HHV$ for ethanol from sugarcane. In second transformation this ranges from 20 for ethanol from maize to 38 $m^3/GJ\ HHV$ for the mixture of biodiesel and ethanol from rape.

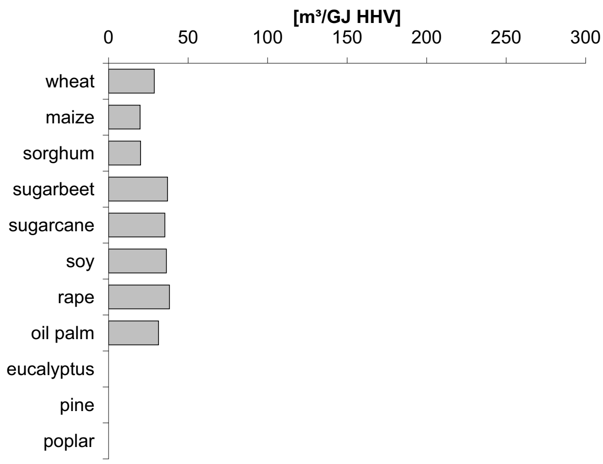
For the HEI-system second transformation also causes water savings. Contrary to the current situation sorghum is not the most water inefficient, but almost the most water efficient crop for the production of liquid biofuels. In the current system first generation ethanol from maize has a virtual water content of 99 $m^3/GJ\ HHV$. In the HEI-system second generation ethanol from maize has a virtual water content of 20 $m^3/GJ\ HHV$. Liquid biofuels based on global averages become 5 times as water efficient by combining the effects of the HEI-system and second transformation.

In the specific case of ethanol from maize produced in the United States, the values are different. In the current system, first generation ethanol from maize has a virtual water content of 72 $m^3/GJ\ HHV$. In the HEI-system second generation ethanol from maize has a virtual water content of 23 $m^3/GJ\ HHV$. For ethanol from sugarcane produced in Brazil or India, or biodiesel from rape produced in Germany, these values are 72 and 36 $m^3/GJ\ HHV$. Therefore, most current liquid biofuels can become only $2-3$ times as water efficient.

Figure 4.33: Average of the virtual water content of secondary energy of crop categories 1-3 in the HEI-system in first and second transformation



(a) First transformation



(b) Second transformation

4.5 Discussion

This research calculated the virtual water content of bioenergy. The basis for bioenergy is primary energy from biomass. This is the product of the overlap of three systems: energy, agriculture, and water. The global average of the virtual water content of primary energy is a function of individual countries and their production share. This research approaches the three systems at a high aggregation level. Therefore values for individual countries can contain a large amount of uncertainty. Aggregation to a global average reduces this uncertainty.

4.5.1 Uncertainty in the energy system

The energy system regards the amount of energy commodities which correspond with one *ton* of total biological yield. In case of primary energy this is the heating value of biomass. Biomass contains an inherent variability, therefore the research uses hypothetical crop compositions. The heating value of these compositions is most sensitive to the fat and mineral content. For all crops there is no reason to doubt these values, two exceptions are rape and oil palm. The selected composition contains a relatively low amount of fats compared to the extraction index (oil content). This causes uncertainty in the heating value of the total biological yield.

4.5.2 Uncertainty in the agriculture system

The agriculture system regards the amount of biomass which is produced per unit surface. In case of primary energy this is the dry total biological yield. This can vary per crop, crop variety, year, country, etc. Therefore the research uses general values for crops and yield values of the period $1997 - 2001$. One of such general values is the harvest index, for maize this varies by 10% for different sources [Goudriaan et al., 2001] [Berndes, 2002]. The use of different time period $(1992-1996)$ gives for wheat from India or the Netherlands a $6-10\%$ change in average yield. These developments in time are negligible compared to the variation in yield, the Netherlands has a wheat yield which is three times the yield of India. This however, is not an uncertainty, but difference which is always present in the yield database [FAO, 2007a].

This research introduced a new way of calculating the irrigation per crop in a country. In the United States 15% of the maize is irrigated (85% is not) [Nadal and Wise, 2004]. This research calculated a value of 6% (94% of the maize is not irrigated). Differences exist between the observed irrigation area and the calculated irrigation area. This is due to data which is of limited quality and the assumption that irrigation is homogenously distributed among all crops. However, both the observation and the new calculation methodology clearly show that the largest part of maize is not irrigated.

Also a new way was introduced for estimating the fertilizer use. It assumes inorganic fertilizer is proportional to the total biological. Yield and nitrogen uptake are proportional to each other [de Wit, 1992]. Therefore, the methodology overlooks other sources of nitrogen (such as organic fertilizer) and losses of nitrogen. The average nitrogen use of wheat in the HEI-system is $10,3\ kg\ N/DM\ ton$. The ratio between the uptake of (all) nitrogen and the production of dry biomass is $14\ kg\ N/DM\ ton$ [Ivens et al., 1992]. Differences exist between the uptake of (all) nitrogen and the calculated nitrogen use. However, both values are of the same magnitude. Therefore, the uptake and the estimation of nitrogen use, which accompanies high yields, are also of the same magnitude.

4.5.3 Uncertainty in the water system

The water system regards the volume of water which is consumed per unit area. In case of primary energy this is green, blue, and grey water. These depend on the water demand, water availability, and pollution by nitrogen. These vary per climate, location, cultivation practice, soil characteristics, etc. Therefore this research uses general values as: averaged monthly weather data, rough estimates for the cultivation practice of many countries, and water availability which only depends on precipitation. The estimates for the cultivation practice have the largest uncertainty. For example soy in Brazil is estimated to have a cultivation period of 85 *days* [Chapagain and Hoekstra, 2004], a more specific source reports a cultivation period which is twice as long [USDA, 1994]. Further, the climate of Brazil allows cultivation in the summer and winter, the water demand of these periods differs by a factor two. Both sources of uncertainty regard individual countries, the global average has therefore a (much) smaller uncertainty.

This research applied the water footprint concept to new crops (trees) which use for their water consumption a different calculation method. This uses a simple formula which combines transpiration and interception. More complex formulae are used by Dolman and Nonhebel [1988]. These use coniferous (pine and spruce) and dedicious species (oak and beech) for the Netherlands. This research also uses a coniferous (pine) and a dedicious species (poplar). Calculated evapotranspiration of pine and poplar is 630 mm/yr and 510 mm/yr, Dolman and Nonhebel [1988] reports for coniferous species $364 - 800$ mm/yr and for dedicious species $307 - 463$ mm/yr. The values of this study are in or close to the range of values reported by Dolman and Nonhebel [1988]. Therefore both methods for calculation of the water consumption of trees is of the same magnitude.

For the above reasons, the results obtained from this study are not considered 'ground-truthing'. The results, however, show a direction at appropriate aggregation levels.

4.5.4 Comparison of results with other researches

The results of this study are compared with three studies, based on four crops. Chapagain and Hoekstra [2004] report global averages of the virtual water content for the wet economic yield (m^3/ton), Gerbens-Leenes et al. [2008] reports for four countries the virtual water content of primary energy ($m^3/GJ\ HHV$), and Berndes [2002] reports ranges of crop water consumption per unit secondary energy (m^3/GJ). This research contains parameters such as the dry mass fraction, with these parameters the results of this research can be presented in the same units as previous researches. Table 4.7 lists a comparison between these previous studies and this research.

The table shows that, in general, the results between various studies are quite comparable with some exceptions. For example maize has the same virtual water content in Chapagain and Hoekstra [2004] as in this study. This is interesting as Chapagain and Hoekstra [2004] assume crop production is not

Table 4.7: Comparison between the results of previous and this study

Product	wet economic yield		primary energy		secondary energy	
Crop	previous[ad] m^3/ton	this study[d] m^3/ton	previous[be] $m^3/GJ\ HHV$	this study[d] $m^3/GJ\ HHV$	previous[ce] m^3/GJ	this study[d] $m^3/GJ\ HHV$
Maize	909	920	9 - 200	25	73 - 346[f]	100[f]
Sorghum	2853	2300	-	35	-	220[f]
Sugarbeet	113	100	13 - 23	20	71 - 188[f]	40[f]
Rape	1611	2600	67 - 210	55	100 - 175[g]	130[g]

a) [Chapagain and Hoekstra, 2004]
b) [Gerbens-Leenes et al., 2008]
c) [Berndes, 2002]
d) Weighted (global) average
e) Reported range of values
f) Ethanol
g) Biodiesel

water limited, while this study does include water limitations/water shortages. Further Chapagain and Hoekstra [2004] do not include grey water, while this study does. Apparently for maize, the water shortage and grey water consumption are of the same magnitude. Sorghum grows in dryer circumstances and receives less fertilizer. Therefore the water shortage and the grey water content are not of the same magnitude, sorghum has therefore a (much) lower virtual water content in this research than in Chapagain and Hoekstra [2004].

Some results between the studies are not quite comparable. Examples are the results of rape of this study compared with Chapagain and Hoekstra [2004] and Gerbens-Leenes et al. [2008] and the results of ethanol from sugarbeet compared with Berndes [2002]. These differences are explained by differences in the methodology. The difference between the virtual water content of rape of Chapagain and Hoekstra [2004] and this study has two major causes. First, contrary to Chapagain and Hoekstra [2004] this study includes grey water which is for rape a large amount (11 $m^3/GJ\ HHV$ or 560 m^3/ton). Second, China is the largest producer of rape, the crop water requirement of rape in this country deviates between the two studies (93 mm vs 350 mm). The difference between the virtual water content of rape of Chapagain and Hoekstra [2004] and this study is caused by different values for the energy content of one unit fresh weight. This study uses for rape an energy content per unit fresh weight a value of 16 $GJ\ HHV/ton$. Gerbens-Leenes et al. [2008] uses for sunflower a value of 18 $GJ\ HHV/ton$, but for rape a value of $6,8$ $GJ\ HHV/ton$. The difference between the virtual water content of ethanol from sugarbeet of Berndes [2002] and this study are caused by (too) low values for the water use efficiency of sugarbeet used by Berndes [2002]. For example values used by Berndes [2002] are unable to explain high yields in countries such as the Netherlands.

This research views the interaction between water and bioenergy from a different perspective and with a different level of detail than previous researches. Differences between these results of multiple studies are not unreasonable, or can be explained. While the results of this study are not considered ‘ground-truthing’, these similarities indicate that the results show a direction with a low degree of uncertainty.

4.5.5 Recommendations for further research

During (execution of) the research, other fields of interest were encountered, which were outside the scope of this research. Three subjects give a basis for further research.

The first subject is that the scope of this study can be expanded. The research excluded other sources of water consumption, such as in the industrial sector. In the case of ethanol from sugarcane the industrial (blue) water consumption is $0,9\ m^3/GJ\ HHV$ ethanol [Smeets et al., 2006]. This is negligible compared to the virtual water content of ethanol from sugarcane ($80\ m^3/GJ\ HHV$). However, the process causes a considerable BOD-pollution [Pimentel and Patzek, 2007] [Moreira, 2007] Chapagain et al. [2006] present a method to express BOD-pollution as grey water consumption (per unit ethanol), this gives a value of $16\ m^3/GJ\ HHV$. The process of oil extraction from oil palm fruit also gives a high BOD-pollution [Okwute and Isu, 2007]. With the same method this gives a grey water consumption (per unit biodiesel) of $30\ m^3/GJ\ HHV$. Both sources of grey water consumption are significant and should not be ignored. However, these values cannot be applied in a widespread fashion. Moreira [2007] states that most of the pollution of ethanol originates from the washing of cane, which makes the value unapplicable to ethanol from other biomass sources. Okwute and Isu [2007] state that Malaysia requires palm oil mills to threat their waste till it's BOD-level is a factor 250 lower. To assess the implications of water consumption in other sectors than the agriculture further research is needed.

The second subject is that bioenergy can be compared with water-energy interactions. This creates a system which either reinforces itself or breaks itself down. An example of such a system is the interaction between bioenergy and desalinization of salt water. Fresh water is consumed to produce (bio)energy. In the second step energy is consumed to produce fresh water (from salt water). Sugarcane consumes $80\ m^3$ to produce $1\ GJ$ of ethanol. With $1\ GJ$ distillation produces $4,8\ m^3$ of fresh water [Gleick, 1994]. Such a system 'loses' $75\ m^3$ water per GJ ethanol. A system, where both bioenergy and distillation are present, would therefore waste water. To assess the implications of other water-energy interactions further research is needed.

The last subject is that the water footprint methodology can be applied to more interactions between water and consumption. Initial researches focussed on food products, such as the consumption and trade of wheat. Hoekstra and Chapagain [2007] applied this also to other consumable products. This research broadened the interaction from consumable products, to consumable services. The water footprint methodology can also be applied to the area of lifestyle or leisure. Rough calculations indicate that the water footprint of soccer or golf are $80.000\ liter/yr/KNVB\ member$ or $140.000\ liter/yr/NGF\ member$. These numbers are about 10% of the annual water footprint of a Dutchman Chapagain and Hoekstra [2004]. To assess more aspects of the interaction between water and consumption further research is needed.

Chapter 5

Conclusions

The consumption of bioenergy has direct relations with the consumption of fresh water. For the production of bioenergy there are different biomass sources, energy commodities, conversion technologies, and production systems. This research has calculated this relationship between bioenergy and fresh water with the water footprint methodology. This includes the production of bioenergy from one unit of biomass, the production of the biomass, and the fresh water consumption of crops. In the analysis, the research included 50 countries, primary energy, secondary energy of two generations, bioenergy consumption, eleven crops, two production systems, and the consumption of three sources of water (green, blue, and grey).

The average water consumption per unit primary energy of biomass produced in the current system ranges from 20 to 80 $m^3/GJ\ HHV$. Sugarcrops and oil palm are the most water efficient sources of primary bioenergy. The least water efficient sources of primary bioenergy are rape, eucalyptus, pine, and poplar. The average water consumption consists for the largest part of green water. Grey water has a large share of 20% in the global average water consumption of maize, sugarbeet, and rape. The average water consumption per unit first generation secondary energy of biomass produced in the current system ranges from 40 $m^3/GJ\ HHV$ for global average of ethanol from sugarbeet to 500 $m^3/GJ\ HHV$ for global average of power from rape (oil). The average water consumption of the liquid biofuels biodiesel and ethanol shows a large variation among crops. With a global average water consumption of 40 $m^3/GJ\ HHV$ sugarbeet is the most efficient source of liquid biofuels, while with a global average water consumption of 200 $m^3/GJ\ HHV$ sorghum is the least efficient source of liquid biofuels. Wood from trees can be used to produce both charcoal and power. From wood twice as much energy is produced in the form of charcoal than power. Therefore, the production of charcoal is twice as water efficient as the production of power per unit energy. As charcoal and power are dissimilar energy commodities, this is only a limited comparison. Power can be produced from oil crops and from trees. However, power from trees is more water efficient than power from oil crops.

Several of the patterns of the average water consumption present themselves for individual countries. However, the absolute volume of water consumption per unit energy and the composition of green, blue and grey water can differ substantially per country. For example sugarcane in India and the United States has the same absolute total water consumption per unit primary energy. In India blue water has of this total water consumption a share of 40%, while in the United States this is only 7%. Countries produce liquid biofuels from crops which are currently one of the most water efficient crops in the country. However, almost all countries have an alternative crop which is equally or more water efficient than the current source for liquid biofuels. Therefore water can be saved, not by changing technology, but by changing choices.

Bioenergy is produced more efficiently in the optimal agricultural system. The HEI-system achieves higher yields for starch-, sugar-, and oilcrops per unit area by increasing the amount of external inputs. The average water consumption per unit primary energy of biomass produced in the HEI system ranges from 10 to 30 $m^3/GJ\ HHV$. The primary energy from sugarcane in the HEI-system is equally water efficient as in the current system. However, primary energy from sorghum becomes three times more water efficient. In the HEI-system blue and grey water play a much larger role than in the current system. The average water consumption of the liquid biofuels (biodiesel and ethanol) from crops in the HEI-system varies only by a small amount per crop. Further, the HEI-system diminishes differences among crops and differences among countries. Crops in countries which are already water efficient show a smaller increase in water efficiency then crops crops which are not.

The optimal system also includes second transformation. This system produces liquid biofuels from the whole plant or tree. Liquid biofuels produced with second transformation are a factor $1,6$ to $3,5$ more water efficient. The most water efficient crops for liquid biofuels are: sugarbeet, sugarcane, and oil palm. The least water efficient source of liquid biofuels are trees. Both components of the optimal system can be combined. In this case, the average water consumption per liquid biofuel ranges from 20 to 40 $m^3/GJ\ HHV$. This is five times as efficient compared to liquid biofuels from the current system. For individual countries, which already use water efficient crops, this is $2-3$ times as water efficient.

This research covered the consumption of ethanol, biodiesel, fuelwood, and wood charcoal. Together their current consumption is 15 $EJ\ HHV/yr$. The total water footprint of this bioenergy consumption is 1500 Gm^3/yr. The consumption of liquid biofuels makes up a small part of the energy consumption (6%) and only 1% of the global water footprint. When the transport sector is fueled with average liquid biofuels, then the global water footprint doubles. Wood fuels make up the largest part of both the energy consumption and the water footprint. Compared to other uses of water, this is also a large volume. When the global coal consumption is replaced with average fuelwood, then the global water footprint doubles or triples. A shift from fossil energy towards bioenergy, therefore, has a large impact on heavily stressed freshwater resources.

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Appendix A

Abbreviations

Table A.1: Abbreviations

Abbreviation	Description
AEZ	Agro Ecological Zones method
ASCE	American Society of Civil Engineers
CI	Conversion Index
CIA	Central Intelligence Agency
CRU	Climate Research Unit
CWR	Crop Water Requirement
CWU	Crop Water Use
DM	Dry Mass
DOE	U.S. Department Of Energy
e_{eq}	Energy Equivalent
e_{tey}	Total Energy Yield
ECN	Energy research Centre of the Netherlands
EI	Extraction Index
FAO	Food and Agriculture Organization of the United Nations
fuelwood-C	Coniferous fuelwood
fuelwood-NC	Non-coniferous fuelwood
GAEZ	Global Agro-Ecological Zones study
GPFA	Global Planted Forest Assessment 2005
HEI	High External Input
HHV	Higher Heating Value
HI	Harvest Index
IEA	International Energy Agency
IR	Irrigation Requirement
LGP	Cultivation period (length of growth period in previous studies)
LHV	Lower Heating Value
NREL	National Renewable Energy Laboratory
UNDP	United Nations Development Programme
USDA	United States Department of Agriculture
WF	Water Footprint

Appendix B

Glossary

Bioenergy Energy from biofuels.

Biofuels Fuels from biomass.

Biomass All material of biological origin, excluding material embedded in geological formations and transformed to fossil.

Blue water The volume of surface water or groundwater that evaporates during production of a product.

Conversion index The ratio of the yield of secondary energy and the extraction yield.

Crop water requirement The water needed for evapotranspiration under ideal growth conditions. This refers to conditions where growth is not limited by water shortages.

Economic yield The part of a crop that provides the economic benefit when it is grown for food or feed purposes, such as the grain of wheat.

Energy equivalent Value of (valuable) byproducts, expressed by energy.

Extraction index The ratio of the extraction yield and the economic yield.

Extraction yield The valuable part in the economic yield that can be extracted, such as sugar in the sugarbeet or oil in oil palm fruit.

First generation conversion processes Aggregate of conversion processes which are currently commercially available.

First transformation Production of secondary energy with first generation conversion processes.

Green water The volume of rainwater that evaporates during production of a product.

Grey water The volume of water that becomes polluted during production of a product.

Harvest index The ratio of the economic yield and the total biological yield.

Higher heating value All heat released by fuels, including latent heat of vaporization of water vapor which is formed during combustion.

Liquid biofuels Ethanol and biodiesel.

Lower heating value Heat released by fuels, excluding latent heat of vaporization of water vapor which is formed during combustion.

Primary energy Energy energy carriers which are extracted directly from nature. In case of bioenergy this refers to the total biological yield.

Residue yield The non-economic part, such as the stems and leaves of wheat.

Rest yield The part of the economic yield which is not the extraction yield, such as beet pulp of sugarbeet.

Secondary energy Energy carriers which are produced from other energy carriers.

Second generation conversion processes Aggregate of conversion processes which are not yet commercially available, but which allow (some) limitations to be overcome.

Second transformation Production of secondary energy which uses the whole crop with (first and) second generation processes.

Total biological yield The sum of the economic yield and the crop residues.

Total energy yield Sum of secondary energy produced from one unit total biological yield.

Virtual water content The volume of freshwater used to produce a product, measured at the place where the product was actually produced.

Water footprint The total volume of freshwater that is consumed to produce the consumed goods and services.

Wood fuels Fuelwood and wood charcoal.

Appendix C

Energy - methodology appendix

Table C.1: Heating values of six components

Component	heating value
Carbohydrates	$17,3\ GJ\ HHV/DM\ ton$
Fats	$37,7\ GJ\ HHV/DM\ ton$
Lignins	$29,9\ GJ\ HHV/DM\ ton$
Minerals	$0\ GJ\ HHV/DM\ ton$
Organic acids	$13,9\ GJ\ HHV/DM\ ton$
Proteins	$22,7\ GJ\ HHV/DM\ ton$

Source: [Penning de Vries et al., 1989]

Table C.2: Hypothetical mass distributions

Hypothetical composition	Carbo-hydrates	Proteins	Fats	Lignins	Organic acids	Minerals
Carbohydrates	100%	-	-	-	-	-
Fats	-	-	100%	-	-	-
Wheat	76%	12%	2%	6%	2%	2%
Maize	75%	8%	4%	11%	1%	1%
Sorghum	72%	9%	3%	12%	2%	2%
Whole beet	82%	5%	-	5%	4%	4%
Whole tops	57%	7%	2%	22%	6%	6%
Soy	29%	37%	18%	6%	5%	5%
Sunflower	45%	14%	22%	13%	3%	3%
Stems	62%	10%	2%	20%	2%	4%
Leaves	52%	25%	5%	5%	5%	8%

Source: [Penning de Vries et al., 1989]

Table C.3: Values of the conversion index

Process	output	heating value	feedstock	conversion index
Fermentation	ethanol	$31,0\ GJ\ HHV/DM\ ton^a$	sugar	$54\%^d$
Fermentation	ethanol	$31,0\ GJ\ HHV/DM\ ton^a$	starch	$57\%^e$
Fermentation	ethanol	$31,0\ GJ\ HHV/DM\ ton^a$	carbohydrates	$57\%^f$
Transesterfication	biodiesel	$39,8\ GJ\ HHV/DM\ ton^b$	oil	$100\%^g$
Slow pyrolysis	charcoal	$31,1\ GJ\ HHV/DM\ ton^c$	round wood	$33\%^h$
Combustion	electricity	-	oil	$27\%^i$
Combustion	electricity	-	round wood	$27\%^i$

a) Source: [ECN, 2007].
b) Source: [DOE, 2007].
c) Source: [Reisinger et al., 2008].
d) This is the theoretical or stoichiometric conversion efficiency. It consists the product of two factors: conversion of glucose to ethanol $(0,51)$, and hydrolysis of sucrose to glucose $(1,05)$. Practical yields are $86,6\%$ of this value [USDA, 2006].
e) This is the theoretical or stoichiometric conversion efficiency. It consists the product of two factors: conversion of glucose to ethanol $(0,51)$, and hydrolysis of starch to glucose $(1,11)$. Reported yields are $83-107\%$ of this value [IEA, 2004].
f) This is the theoretical or stoichiometric conversion efficiency of cellulose. It consists the product of two factors: the conversion of glucose to ethanol $(0,51)$, and hydrolysis of cellulose to glucose $(1,11)$ [NREL, 2008]. Reported yields are 70% of this value [Reith et al., 2002].
g) This is the theoretical or stoichiometric conversion efficiency [Pleanjai et al., 2004]. Reported yields are $98-100\%$ of this value [Pimentel and Patzek, 2005].
h) Source: [Drigo, 2005] This corresponds with an energy efficiency of 50%. Reported energy efficiency of charcoal production ranges from 25% in Africa to 48% in Brazil [Zupanc, 2007].
i) The conversion index of electricity refers to the energy conversion. This energy conversion is based on the higher heating value. Source: [IEA, 1994]

Appendix D

Agriculture - methodology appendix

Table D.1: Values of the harvest index

Crop	crop part	harvest index	literature values
Wheat	ear, grain	45%	45% [Goudriaan et al., 2001], 45% [Berndes, 2002],
Maize	cob, grain	45%	45% [Goudriaan et al., 2001], 40% [Berndes, 2002], 45% [Andrade, 1995]
Sorghum	ear, grain	27%	27% [Goudriaan et al., 2001]
Sugarbeet	beet	66%	66% [Goudriaan et al., 2001], 60% [Berndes, 2002]
Sugarcane	cane	60%	60% [Goudriaan et al., 2001], 60% [Berndes, 2002]
Soy	seed	40%	40% [Goudriaan et al., 2001], 37% [Andrade, 1995],
Rape	seed	32%	32% [Habekotte, 1997], 28% – 50% [Rathke et al., 2005], 50% [Berndes, 2002]
Oil palm	fruit bunch	45%	46% [Wahid et al., 2004], 37,3% – 50,7% [Corley and Lee, 1992]
Eucalyptus	round wood	75%	80% [Berndes, 2002], 75% [Kassam et al., 1991]
Pine	round wood	75%	-
Poplar	round wood	75%	-

Table D.2: Values of the extraction index

Crop	crop part	extraction index	literature values
Wheat	starch/ear	59%[a]	79% flour [FAO, 2000]
Maize	starch/cob	62%[a]	82% flour, starch content of flour 75% [FAO, 2000]
Sorghum	starch/ear	68%[a]	90% flour [FAO, 2000]
Sugarbeet	sugar/beet	70%	70% [Berndes, 2002]
	sugar/total crop		35% – 50% [Ober et al., 2004]
Sugarcane	sugar/stalk	45%	45% [Berndes, 2002], 49% [Muchow et al., 1996]
Soy	oil/seed	20%[b]	18%[d] [FAO, 2000]
Rape	oil/seed	45%	43,8% – 47,7% [Rathke et al., 2005]
			38%[d] [FAO, 2000]
Oil palm	mesocarp oil/bunch	40%[c]	19%[d] [FAO, 2000]
	mesocarp oil/total crop		18,5% [Wahid et al., 2004]
Eucalyptus	-	-	-
Pine	-	-	-
Poplar	-	-	-

a) The extraction index is calculated with the amount of flour that is produced from the grain and the starch content of this flour. This research uses the starch content of flour of maize flour
b) The extraction index is based on the wet oil content listed in [FAO, 2000] and the dry mass content listed in [Goudriaan et al., 2001]
c) The extraction index is based on the oil content of the whole plant listed in [Wahid et al., 2004] and the harvest index listed in [Wahid et al., 2004]
d) Values refer to wet biomass

Table D.3: Reported yield and the yield correction factor for crop yields from the Faostat database

Crop	economic yield	reported yield[a]	correction factor
Wheat	ear + grain (dry mass)	ear + grain (wet mass)	85%[b]
Maize	cob + grain (dry mass)	cob + grain (wet mass)	85%[b]
Sorghum	ear + grain (dry mass)	ear + grain (wet mass)	88%[b]
Sugarbeet	beet (dry mass)	beet (wet mass)	21%[b]
Sugarcane	cane (dry mass)	cane (wet mass)	27%[b]
Soy	seed (dry mass)	seed (wet mass)	92%[b]
Rape	seed (dry mass)	seed (wet mass)	74%[c]
Oil palm	Bunch (dry mass)	bunch (wet mass)	60%[d]

a) Source: [FAO, 2007a]
b) Source: [Goudriaan et al., 2001]
c) Source: [Habekotte, 1997]
d) Dry matter content of a bunch is based on the extraction index and the oil content of wet fruit.

Table D.4: Reported yield and the yield correction factor for crop yields from the GPFA database

Crop	economic yield	reported yield	correction factor
Eucalyptus	round wood (dry mass)	growing stock (volume)	500 kg/m^3
Pine	round wood (dry mass)	growing stock (volume)	500 kg/m^3
Poplar	round wood (dry mass)	growing stock (volume)	500 kg/m^3

a) Dry density is based on the wet density of 725 kg/m^3 and 30% moisture content [Drigo, 2005]

Table D.5: Reported yield and the yield correction factor for crop yields from the GAEZ database

Crop	economic yield	reported yield[a]	correction factor
Wheat	ear + grain (dry mass)	grain (dry mass)	100%
Maize	cob + grain (dry mass)	grain (dry mass)	100%
Sorghum	ear + grain (dry mass)	grain (dry mass)	100%
Sugarbeet	beet (dry mass)	sugar (dry mass)	143%[b]
Sugarcane	stalk (dry mass)	sugar (dry mass)	222%[b]
Soy	seed (dry mass)	seed (dry mass)	100%
Rape	seed (dry mass)	seed (dry mass)	100%
Oil palm	bunch (dry mass)	mesocarp oil (dry mass)	250%[b]

a) Source: [Kassam et al., 1991] [Fischer et al., 2000]
b) Correction factors are based on the extraction index

Table D.6: Criteria for thermal climate classification

Climate region	Criteria[a]
Tropics	All months with monthly mean temperatures, corrected to sea level above 18^oC
Subtropics	One or more months with monthly mean temperatures, corrected to sea level below 18^oC but above 5^oC
Subtropics, summer rainfall	Northern hemisphere: rainfall April - September > rainfall October - March Southern hemisphere: rainfall October - March > rainfall April - September
Subtropics, winter rainfall	Northern hemisphere: rainfall October - March > rainfall April - September Southern hemisphere: rainfall April - September > rainfall October - March
Temperate	At least one month with monthly mean temperatures, corrected to sea level, below 5^oC and four or more months above 10^oC
Oceanic temperate	Seasonality[b] less than 20^oC
Sub-continental temperate	Seasonality[b] between $20 - 35^oC$
Continental temperate	Seasonality[b] more than 35^oC
Boreal	At least one month with monthly mean temperatures, corrected to sea level, below 5^oC and one to three months above 10^oC
Oceanic boreal	Seasonality[b] less than 20^oC
Sub-continental boreal	Seasonality[b] between $20 - 35^oC$
Continental boreal	Seasonality[b] more than 35^oC
Polar/arctic	All months with monthly mean temperatures, corrected to sea level, below 10^oC

a) Source: [Fischer et al., 2000] [Chapagain and Hoekstra, 2004]
b) Seasonality refers to the difference in mean temperature of the warmest and coldest month

Table D.7: Length of cultivation periods of crops by climate zone

Crop[a]	tropics	subtropics summer rainfall	subtropics winter rainfall	oceanic temperate	sub-continental, continental temperate	sub-continental, continental boreal, polar
Wheat, winter[b]	-	-	-	335	335	335
Wheat, spring	120	120	180	180	180	180
Maize	125	125	150	150	150	150
Sorghum	125	125	125	125	130	130
Sugarbeet	205	230	180	180	180	180
Sugarcane	365	365	365	365	365	365
Soya	85	135	135	150	150	150
Rape	150	150	150	180	180	180
Oil palm	365	365	365	365	365	365

a) Source: [Chapagain and Hoekstra, 2004]
b) When data are available wheat is modeled as winter wheat

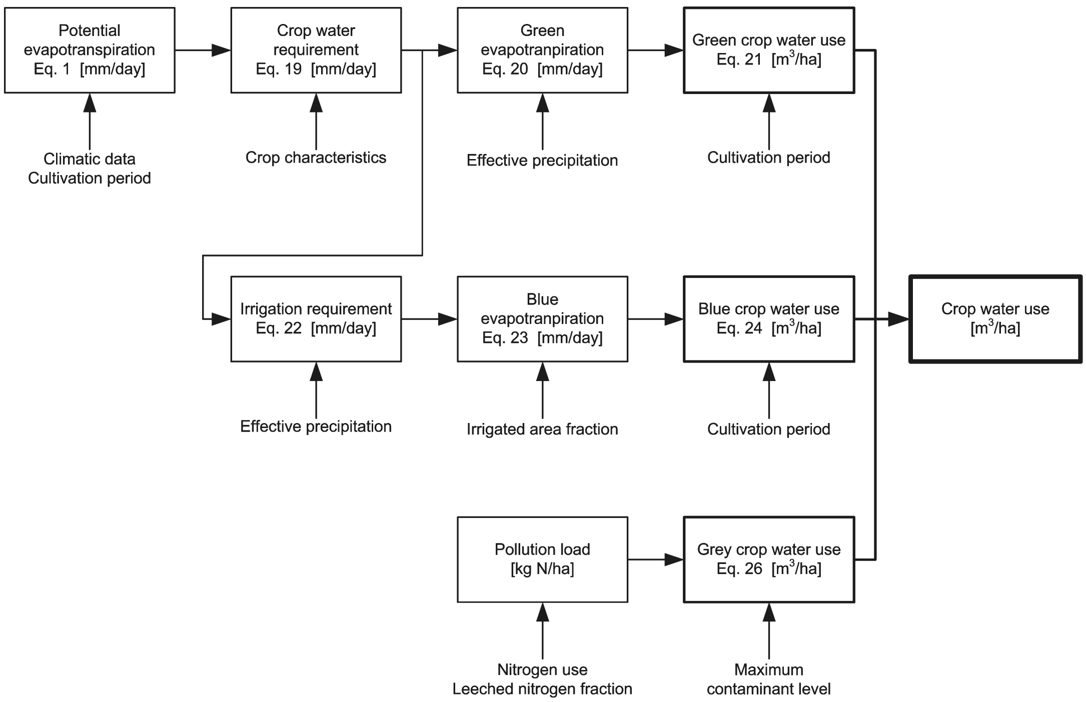
Appendix E

Water - methodology appendix

E.1 Water methodology - calculation procedure

This section describes the calculation of crop water use (CWU, m^3/ha). It consists of a green, blue and grey component. Figure E.1 gives an overview of the steps which are taken to calculate the crop water use.

Figure E.1: Steps in the calculation of the crop water use.



The section contains four sub-sections. The first sub-sections describes the calculation of the potential evaporation. The second, third and fourth sub-sections describe the calculation of the green crop water use, blue crop water use, and grey crop water use.

E.1.1 Potential evapotranspiration

The potential evapotranspiration (ET_0, mm/day) depends on the location and has seasonal changes. The ET_0 is calculated for all months and for each location of crop cultivation. Calculation uses the Penman-Monteith formula. Calculation uses guidelines listed in [Allen et al., 1998], which are used in [Chapagain and Hoekstra, 2004]. This research uses the following parameters from the CRU CL 2.0 database for the calculation of the ET_0.

- Average temperature (T, ^oC)
- Diurnal temperature, difference between minimum and maximum temperature (T_{diur}, ^oC)
- Elevation (z, m)
- Relative humidity (Reh, $-$)
- Relative sunshine duration (n/N, $-$)
- Wind speed measured at 10 m height (U_{10}, m/s)

Figure E.2 shows the steps which are taken to calculate the parameters for the evapotranspiration. Here non-boxed parameters are available input and boxed parameters are calculated with the available input. Equation E.1 through E.18 list the formulas and constants which are used.

Table E.1: Penman-Monteith formula

$$ET_0 = \frac{0,408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0,34U_2)} \tag{E.1}$$

ET_0	potential evaporation [mm/day]
Δ	slope of the vapour pressure curve [$kPa/^oC$] (equation E.2)
R_n	net radiation at the crop surface [$MJ/m^2/day$] (equation E.6)
G	soil heat flux [$MJ/m^2/day$] (equation E.15)
γ	psychometric constant [$kPa/^oC$] (equation E.16)
T	average air temperature [^oC]
U_2	wind speed measured at 2 m height [m/s] (equation E.18)
e_s	saturation vapour pressure [kPa] (equation E.3)
e_a	actual vapour pressure [kPa] (equation E.5)
$e_s - e_a$	vapour pressure deficit [kPa]

Figure E.2: Steps of the calculation of the potential evapotranspiration

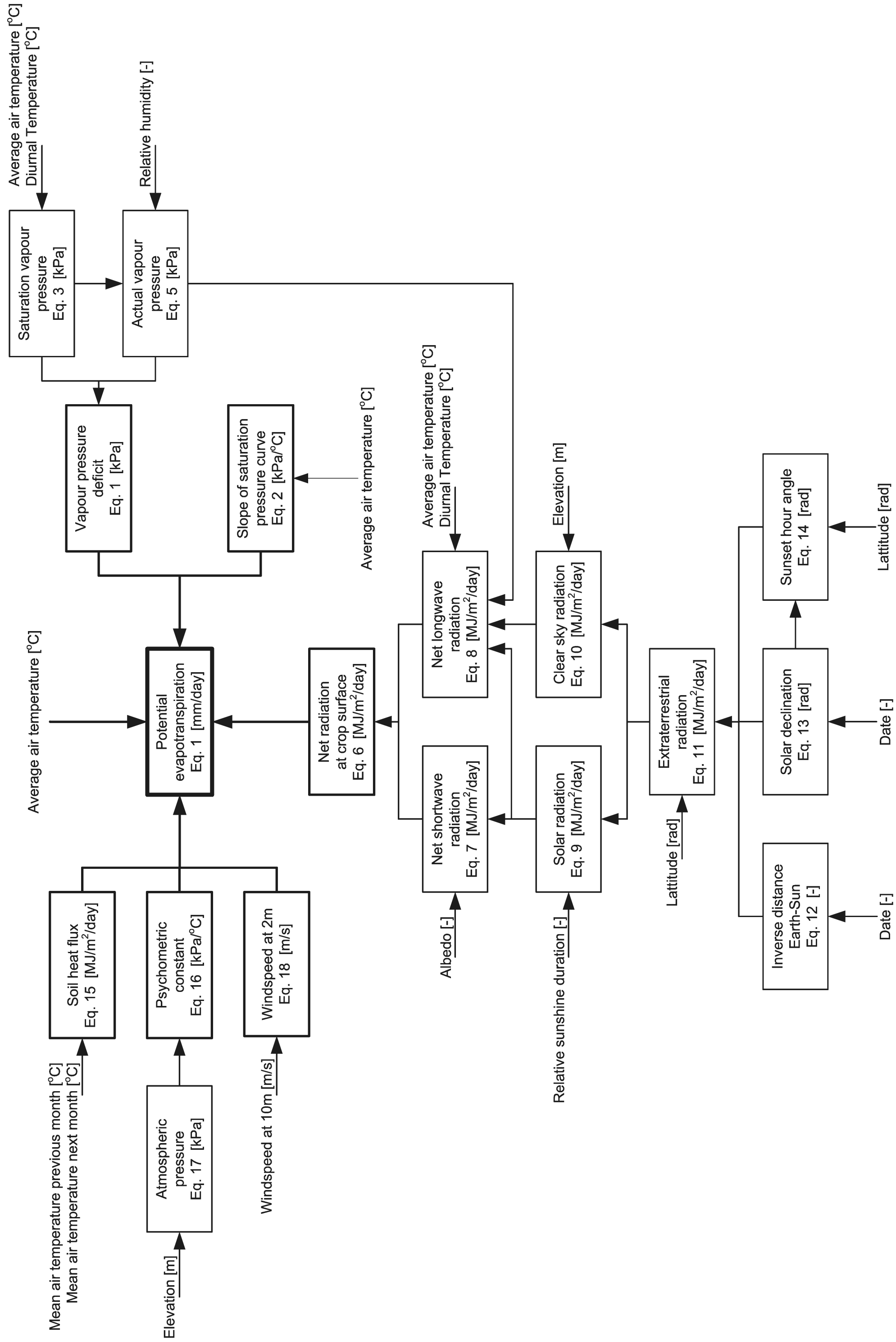


Table E.2: Slope of the vapour pressure curve

$$\Delta = \frac{4098 * [0,6108 * exp(\frac{17,27*T}{T+237,3})]}{(T+237,3)^2} \tag{E.2}$$

Δ	slope of the vapour pressure curve $[kPa/^oC]$
T	average air temperature $[^oC]$
$exp(..)$	$2,71828$ raised to the power (..)

Table E.3: Saturation vapour pressure

$$e_s = \frac{e^0(T + 0,5T_{diur}) + e^0(T - 0,5T_{diur})}{2} \tag{E.3}$$

$$e^0(T) = 0,6108 * exp(\frac{17,27 * T}{T + 237,3}) \tag{E.4}$$

e_s	saturation vapour pressure $[kPa]$
T	average air temperature $[^oC]$
T_{diur}	diurnal temperature, difference between minimum and maximum temperature $[^oC]$
$e^0(T)$	saturation vapour pressure at temperature T $[kPa]$ (equation E.4)

Table E.4: Actual vapour pressure

$$e_a = e_s * Reh \tag{E.5}$$

e_a	actual vapour pressure $[kPa]$
e_s	saturation vapour pressure $[kPa]$ (equation E.3)
Reh	relative humidity $[-]$

Table E.5: Net radiation

$$R_n = R_{ns} - R_{nl} \tag{E.6}$$

R_n	net radiation at the crop surface $[MJ/m^2/day]$
R_{ns}	incoming net shortwave radiation at the crop surface $[MJ/m^2/day]$ (equation E.7)
R_{nl}	outgoing net longwave radiation at the crop surface $[MJ/m^2/day]$ (equation E.8)

Table E.6: Incoming net shortwave radiation at the crop surface

$$R_{ns} = (1 - \alpha)R_s \tag{E.7}$$

R_{ns}	incoming net shortwave radiation at the crop surface $[MJ/m^2/day]$
α	albedo or canopy reflection coefficient, for crop categories 1-3 this is $0,23$
R_s	incoming solar radiation at the crop surface $[MJ/m^2/day]$ (equation E.9)

Table E.7: Outgoing net longwave radiation at the crop surface

$$R_{nl} = \sigma \frac{T^4_{(T,K+0,5T_{diur})} + T^4_{(T,K-0,5T_{diur})}}{2}(0,34 - 0,14\sqrt{e_a}) * (1,35\frac{R_s}{R_{s0}} - 0,35) \tag{E.8}$$

R_{nl}	outgoing net longwave radiation at the crop surface $[MJ/m^2/day]$
σ	Stefan-Boltzmann constant, $4,903 * 10^{-9}\ MJ/K^4/m^2/day$
T, K	average absolute air temperature $[K =^o C + 273,16]$
T_{diur}	diurnal temperature, difference between minimum and maximum temperature $[^oC]$
e_a	actual vapour pressure $[kPa]$ (equation E.5)
R_s/R_{s0}	relative short wave radiation (limited to $\leq\ 1,0$)
R_s	solar radiation $[MJ/m^2/day]$ (equation E.9)
R_{s0}	clear-sky radiation $[MJ/m^2/day]$ (equation E.10)

Table E.8: Solar radiation

$$R_s = (a_s + b_s * \frac{n}{N}) * R_a \tag{E.9}$$

R_s	solar radiation $[MJ/m^2/day]$
a_s	regression constant, expressing the fraction of extraterrestrial radiation reaching earth on over cast days ($n = 0$). No actual data is available, this research uses the value of $0,25$
b_s	regression constant, expresses together with a_s the fraction of extraterrestrial radiation reaching earth on clear days ($n = N$). No actual data is available, this research uses the value of $0,50$
n/N	relative sunshine duration $[-]$
R_a	extraterrestrial radiation $[MJ/m^2/day]$ (equation E.11)

Table E.9: Solar radiation

$$R_{s0} = (0,75 + 2 * 10^{-6} * z) * R_a \tag{E.10}$$

R_{s0}	clear sky radiation $[MJ/m^2/day]$
z	elevation above mean sea level $[m]$
R_a	extraterrestrial radiation $[MJ/m^2/day]$ (equation E.11)

Table E.10: Extraterrestrial radiation

$$R_a = \frac{24 * 60}{\pi} * G_{sc} * d_r * [\omega_s \sin(\varphi) * \sin(\delta) + \cos(\varphi) * \cos(\delta) * sin(\omega_s)] \quad (E.11)$$

R_a	extraterrestrial radiation $[MJ/m^2/day]$
G_{sc}	solar constant, $0,0820\ MJ/m^2/min$
d_r	inverse relative distance Earth-Sun $[-]$ (equation E.12)
ω_s	sunset hour angle $[rad]$ (equation E.14)
φ	latitude $[rad]$
δ	solar decimation $[rad]$ (equation E.13)

Table E.11: Inverse relative distance Earth-Sun, and the solar declination

$$d_r = 1 + 0,033 * \cos(\frac{2\pi}{365}J) \quad (E.12)$$

$$\delta = 0,409 * \sin(\frac{2\pi}{365}J - 1,39) \quad (E.13)$$

d_r	inverse relative distance Earth-Sun [-]
δ	solar decimation $[rad]$
J	day number, 1st of January is day 1, 31th of December is day 365 $[-]$

Table E.12: Sunset hour angle

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)] \quad (E.14)$$

ω_s	sunset hour angle $[rad]$
δ	solar decimation $[rad]$ (equation E.13)
φ	latitude $[rad]$

Table E.13: Soil heat flux

$$G_{month,i} = 0,07 * (T_{month,i+1} - T_{month,i-1}) \quad (E.15)$$

$G_{month,i}$	monthly average of the soil heat flux per day in month i $[MJ/m^2/day]$
$T_{month,i+1}$	average air temperature in the next month $[^oC]$
$T_{month,i-1}$	average air temperature in the previous month $[^oC]$

Table E.14: Psychometric constant

$$\gamma = \frac{c_p * P}{\varepsilon * \lambda} = 0,665 * 10^{-3} * P \qquad \text{(E.16)}$$

γ	psychometric constant $[kPa/^oC]$
c_p	specific heat at constant pressure, $1,013 * 10^{-3}$ $MJ/kg/^oC$
P	atmospheric pressure [kPa] (equation E.17)
ε	ratio molecular weight of water vapour/dry air, $0,622$
λ	latent heat of vaporization, $2,45$ MJ/kg

Table E.15: Atmospheric pressure

$$P = 101,3 * (\frac{293 - 0,0065 * z}{293})^{5,26} \qquad \text{(E.17)}$$

P	atmospheric pressure $[kPa]$
z	elevation above mean sea level $[m]$

Table E.16: Wind speed

$$U_2 = U_{mz} \frac{4,87}{Ln(67,8 * mz - 5,42)} \qquad \text{(E.18)}$$

U_2	wind speed measured at 2 m height $[m/s]$
U_{mz}	wind speed measured at a height of mz $[m/s]$
mz	height of wind speed measurement $[m]$

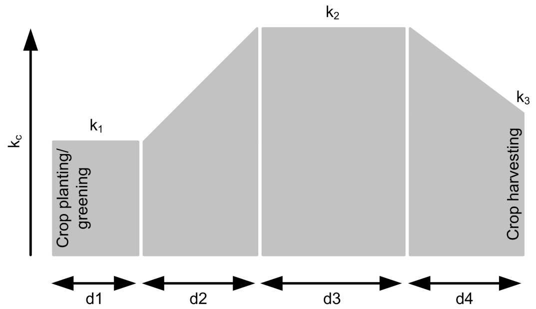
E.1.2 Green crop water use

Several water footprint studies use the CropWat model in their assessment of the crop water use [Chapagain et al., 2006] [Gerbens-Leenes et al., 2008]. The CropWat model is unable to determine the climate or model trees. For consistency reasons the research calculates all parameters manually and does not use the CropWat model. It still uses it's 'CropWat method'. This method calculates the crop water requirement of a crop (CWR, mm/day), the water needed for evapotranspiration under ideal growth conditions. This refers to conditions where growth is not limited by water shortages [Hoekstra and Chapagain, 2008]. Calculation of the crop water requirement uses the potential evapotranspiration (ET_0, mm/day) and the crop coefficient (k_c, $-$). Equation E.19 shows the calculation of the crop water requirement [Allen et al., 1998].

$$CWR = k_c * ET_0 \tag{E.19}$$

The crop coefficient varies during the cultivation period. The method identifies four crop stages during the cultivation period ($d1$ to $d4$). Figure E.3 shows how the k_c value varies per crop stage.

Figure E.3: Variation of crop constant during the four growth stages



Source: [Allen et al., 1998]

A growth stage can be expressed as percentage of the cultivation period (LGP, $days$), this is the relative length of the growing stage. Appendix table E.17 lists the relative length of growing stages and k_c values of crops.

The green crop water use (CWU_{green}, m^3/ha) is the sum of the green water evapotranspiration (ET_{green}, mm/day) over the cultivation period, a factor 10 converts the unit mm into m^3/ha. The volume available green water limits the green water evapotranspiration. In this research available green water is the effective precipitation ($P_{effective}$, mm/day). Effective precipitation is the portion of precipitation which enters the soil [Clarke, 1998]. Equations E.20 and E.21 show the calculation of the green water evapotranspiration and the green crop water use.

$$ET_{green} = min(CWR, P_{effective}) \tag{E.20}$$

$$CWU_{green} = 10 \sum_{d=1}^{LGP} ET_{green} \tag{E.21}$$

The effective precipitation is calculated with the USDA SCS method from the CropWat model [Clarke, 1998] [FAO, 2008]. This research adds a factor 1/30 to this method to get daily values.

The crop water requirement, effective precipitation and green crop water use are calculated for a location. When the research includes more than one location in a country for a crop, these parameters are calculated for each of the locations. Further calculations are based on the (unweighted) average of these three parameters.

E.1.3 Blue crop water use

The blue crop water use (CWU_{blue}, m^3/ha) is the sum of the blue water evapotranspiration over the growth period (LGP, $days$). The blue water evapotranspiration (ET_{blue}, mm/day) is determined by the irrigation requirement (IR, mm/day) and the effective irrigation ($I_{effective}$, mm/day). The effective irrigation is the volume of water which is available for plant uptake. The irrigation requirement (IR, mm/day) is the difference between the crop water requirement (CWR, mm/day) and the effective precipitation ($P_{effective}$, mm/day). Equations E.22, E.23, and E.24 show the calculation of the irrigation requirement, blue water evapotranspiration, and the blue crop water.

$$IR = max(0, CWR - P_{effective}) \tag{E.22}$$

$$ET_{blue} = min(IR, I_{effective}) \tag{E.23}$$

$$CWU_{blue} = 10 \sum_{d=1}^{LGP} ET_{blue} \tag{E.24}$$

Calculation of the effective irrigation ($I_{effective}$, mm/day) uses the irrigation requirement (IR, mm/day) and the fraction in which the requirement is met. The area which is equipped for irrigation uses this equipment to fully satisfy the irrigation requirement. This research assumes that excess irrigation water flows back into the water system, resulting in zero loss. The fraction in which the irrigation requirement is met is therefore the same as the fraction of the area which is equipped for irrigation (f_{iA}, $-$). Equation E.25 shows the calculation of the effective irrigation.

$$I_{effective} = IR * f_{iA} \tag{E.25}$$

E.1.4 Grey crop water use

The grey crop water use is the volume of water that is needed to dilute pollution from nitrogen, which leeches into ground- and surface water.

Calculation of the grey crop water consumption (CWU_{grey}, m^3/ha) uses the pollution load ($Load_N$, $kg\ N/ha$) and the volume of water which is necessary to dilute one unit of nitrogen. Calculation of the pollution load of nitrogen uses the average use of nitrogen (N_{use}, $kg\ N/ha$) and the fraction of nitrogen which leeches into the ground- or surface water ($f_{leeching}$, $-$). The leeched fraction of nitrogen is 10% of the applied (inorganic) fertilizer. This is the same value as was used for the grey component of cotton [Chapagain et al., 2006]. The volume of water that is necessary to dilute one unit of nitrogen is based on the maximum contaminant level (f_{mcl}, $kg\ N/m^3$), this has a value of 10 $mg\ N/L$ [Chapagain et al., 2006]. Equation E.26 shows the calculation of the grey crop water use.

$$CWU_{grey} = \frac{Load_N}{f_{mcl}} = \frac{N_{use} * f_{leeching}}{f_{mcl}} \tag{E.26}$$

E.2 Water methodology - appendix tables

Table E.17: Relative length of growing stages and k_c values of crop categories 1-3

Crop	d_1	d_2	d_3	d_4	k_1	k_2	k_3
Wheat, winter[a]	10%	30%	35%	25%	0,40	1,10	0,40
Wheat, spring[a]	10%	20%	45%	25%	0,40	1,10	0,40
Maize[a]	15%	30%	35%	20%	0,40	1,10	0,60
Sorghum[a]	10%	25%	40%	25%	0,40	1,05	0,55
Sugarbeet[a]	15%	30%	35%	20%	0,50	1,10	0,70
Sugarcane[b]	10%	15%	55%	20%	0,40	1,25	0,75
Soya[a]	15%	20%	45%	20%	0,40	1,10	0,50
Rape[a]	15%	25%	40%	20%	0,50	1,10	0,50
Oil palm[b]	35%	15%	25%	25%	0,90	0,95	0,95

a) Source: [Fischer et al., 2000]
b) Source: [Chapagain and Hoekstra, 2004]

Table E.18: Literature values of the albedo of forests

Crop/forest	albedo	source
Eucalyptus	0,20	value in this study
Pine	0,10	value in this study
Poplar	0,20	value in this study
Dedicious forest	0,15 - 0,25	[ASCE, 1996]
Dedicious forest, bare	0,15	[Ward and Robinson, 1990]
Dedicious forest, leafed	0,20	[Ward and Robinson, 1990]
Hardwoods	0,15 - 0,20	[Chang, 2003]
Coniferous forest	0,05 - 0,15	[Ward and Robinson, 1990]
Coniferous forest	0,10 - 0,15	[ASCE, 1996]
Forest, spruce	0,05 - 0,10	[Chang, 2003]

Table E.19: Intercepted fraction of precipitation

Crop/forest	α_i	location	source
Eucalyptus	14%	average	[Zang et al., 1999]
Pine	28%	average	[Zang et al., 1999]
Poplar	14,9%	Canada	[Mahendrappa, 1990]
Eucalyptus	8,3% - 23,3%	-	[Zang et al., 1999]
Pine	19,1% - 38,1%	-	[Zang et al., 1999]
Coniferous forests	27% - 42%	Great Britain	[Gash et al., 1980]
Northern Hardwood	19,3%	Canada	[Carlyle-Moses, 2004]

Appendix F

Water footprint of bioenergy - methodology appendix

Table F.1: Value and product fractions of the production of secondary energy carriers for first transformation

Crop	secondary energy	${f_p}^a$ a[d]	f_v b	f_p c	f_v d	${f_p}^b$ e	f_v f	f_p g	f_v h	${f_p}^c$ i	f_v j
Wheat	ethanol	0,45	1,00	0,55	-	0,59	1,00	0,41	-	0,57	1,00
Maize	ethanol	0,45	1,00	0,55	-	0,62	1,00	0,38	-	0,57	1,00
Sorghum	ethanol	0,27	1,00	0,73	-	0,68	1,00	0,32	-	0,57	1,00
Sugarbeet	ethanol	0,66	1,00	0,34	-	0,70	1,00	0,30	-	0,54	1,00
Sugarcane	ethanol	0,60	1,00	0,40	-	0,45	1,00	0,55	-	0,54	1,00
soy	biodiesel	0,40	1,00	0,60	-	0,20	0,34[e]	0,80	0,66[e]	1,00	1,00
Rape	biodiesel	0,32	1,00	0,68	-	0,45	0,67[e]	0,55	0,33[e]	1,00	1,00
Oil palm	biodiesel	0,45	1,00	0,55	-	0,40	0,93[e]	x	0,07[e]	1,00	1,00
soy	power	0,40	1,00	0,60	-	0,20	0,34[e]	0,80	0,66[e]	0,27[f]	1,00
Rape	power	0,32	1,00	0,68	-	0,45	0,67[e]	0,55	0,33[e]	0,27[f]	1,00
Oil palm	power	0,45	1,00	0,55	-	0,40	0,93[e]	x	0,07[e]	0,27[f]	1,00
Eucalyptus	power	0,75	1,00	0,25	-	x	x	x	x	0,27[f]	1,00
Pine	power	0,75	1,00	0,25	-	x	x	x	x	0,27[f]	1,00
Poplar	power	0,75	1,00	0,25	-	x	x	x	x	0,27[f]	1,00
Eucalyptus	charcoal	0,75	1,00	0,25	-	x	x	x	x	0,33	1,00
Pine	charcoal	0,75	1,00	0,25	-	x	x	x	x	0,33	1,00
Poplar	charcoal	0,75	1,00	0,25	-	x	x	x	x	0,33	1,00

a) Values correspond with the harvest index
b) Values correspond with the extraction index
c) Values correspond with the conversion index
d) The labels $a - j$ correspond with figure 3.3 in the methodology chapter
e) Source: [Chapagain and Hoekstra, 2004]
f) Product fraction refers to the energy conversion of oil to power or round wood to power.

Table F.2: Aggregated product fractions and energy equivalents of the production of secondary energy carriers for first transformation

Crop	secondary energy	$f_p(secondary)$	e_{eq}
		$-$	$GJ\ HHV/DM\ ton$
Wheat	ethanol	0,15	-
Maize	ethanol	0,16	-
Sorghum	ethanol	0,10	-
Sugarbeet	ethanol	0,25	-
Sugarcane	ethanol	0,15	-
Soy	biodiesel	0,08	6,18
Rape	biodiesel	0,14	2,82
Oil palm	biodiesel	0,18	0,54
Eucalyptus	charcoal	0,25	-
Pine	charcoal	0,25	-
Poplar	charcoal	0,25	-

Table F.3: Product fractions of the production of secondary energy carriers for second transformation

Crop	${f_p}^a$	${f_p}^b$	${f_p}^c$	f_p	${f_p}^b$	${f_p}^c$
	a[d]	b	c	d	e	f
Wheat	0,45	0,76	0,57	0,55	0,62	0,57
Maize	0,45	0,75	0,57	0,55	0,62	0,57
Sorghum	0,27	0,72	0,57	0,73	0,62	0,57
Sugarbeet	0,66	0,82	0,57	0,34	0,52	0,57
Sugarcane	0,60	0,57	0,57	0,40	0,52	0,57
Soy	0,40	0,20	1,00	0,60	0,62	0,57
Rape	0,32	0,45	1,00	0,68	0,62	0,57
Oil palm	0,45	0,40	1,00	0,55	0,62	0,57
Eucalyptus	0,75	0,62	0,57	0,25	0,52	0,57
Pine	0,75	0,62	0,57	0,25	0,52	0,57
Poplar	0,75	0,62	0,57	0,25	0,52	0,57

a) Values correspond with the harvest index
b) Values correspond with either the carbohydrate content or oil content
c) Values correspond with the conversion index
d) The labels $a - f$ correspond with figure 3.4 in the methodology chapter

Table F.4: Aggregated product fractions and energy equivalents of the production of secondary energy carriers for second transformation

Crop	$f_p(biodiesel)$	$f_p(ethanol)$	e_{eq}
	$-$	$-$	$GJ\ HHV/DM\ ton$
Wheat	-	0,39	-
Maize	-	0,39	-
Sorghum	-	0,37	-
Sugarbeet	-	0,41	-
Sugarcane	-	0,31	-
Soy	0,08	0,21	6,18
Rape	0,14	0,24	2,82
Oil palm	0,18	0,19	0,54
Eucalyptus	-	0,34	-
Pine	-	0,34	-
Poplar	-	0,34	-

Appendix G

Energy - results appendix

G.1 Energy content of biomass

Table G.1: Calculated heating values (*GJ HHV/DM ton*)

Crop	extraction yield	rest yield	economic yield	residue yield	total biological yield
Wheat	17,3	20,7	18,7	20,0	19,4
Maize	17,3	23,6	19,7	20,0	19,9
Sorghum	17,3	24,2	19,5	20,0	19,9
Sugarbeet	17,3	17,6	17,4	18,7	17,8
Sugarcane	17,3	21,5	19,6	18,7	19,3
Soya	37,7	18,8	22,6	20,0	21,0
Rape	37,7	11,9	23,5	20,0	21,1
Oil palm	37,7	14,0	23,5	20,0	21,6
Eucalyptus	-	-	20,0	18,7	19,7
Pine	-	-	20,0	18,7	19,7
Poplar	-	-	20,0	18,7	19,7

G.2 Conversion of biomass into secondary energy

Table G.2: First transformation liquid biofuels per ton of total biological yield (*GJ HHV/DM ton*)

Crop	ethanol	biodiesel	energy equivalent	total
wheat	4,69	-	-	4,69
maize	4,93	-	-	4,93
sorghum	3,24	-	-	3,24
sugarbeet	7,73	-	-	7,73
sugarcane	4,52	-	-	4,52
soy	-	3,18	6,18	9,36
rape	-	5,73	2,82	8,55
oil palm	-	7,16	0,54	7,70
eucalyptus	-	-	-	-
pine	-	-	-	-
poplar	-	-	-	-

Table G.3: Power and charcoal per ton of total biological yield (*GJ HHV/DM ton*)

Crop	power	energy equivalent	total power	charcoal
wheat	-	-	-	-
maize	-	-	-	-
sorghum	-	-	-	-
sugarbeet	-	-	-	-
sugarcane	-	-	-	-
soy	0,81	0,42	1,23	-
rape	1,47	0,72	2,19	-
oil palm	1,83	0,14	1,97	-
eucalyptus	4,05	-	4,05	7,70
pine	4,05	-	4,05	7,70
poplar	4,05	-	4,05	7,70

Table G.4: Second transformation liquid biofuels per ton of total biological yield (*GJ HHV/DM ton*)

Crop	ethanol	biodiesel	energy equivalent	total
wheat	12,07	-	-	12,07
maize	11,99	-	-	11,99
sorghum	11,43	-	-	11,43
sugarbeet	11,82	-	-	11,82
sugarcane	9,72	-	-	9,72
soy	6,57	3,18	6,18	15,94
rape	7,45	5,73	2,82	16,00
oil palm	6,03	7,16	0,54	13,73
eucalyptus	10,51	-	-	10,51
pine	10,51	-	-	10,51
poplar	10,51	-	-	10,51

G.3 Consumption of bioenergy in 2005

Table G.5: Feedstock and consumption of biodiesel and ethanol in 2005

Country	ethanol		biodiesel	
	feedstock	consumption[a] $PJ\ HHV/yr$	feedstock	consumption[a] $PJ\ HHV/yr$
Australia	sugarcane[b]	0,5	-	-
Austria	-	-	rape[c]	3,7
Brazil	sugarcane[b]	348,1	-	-
Canada	wheat[b]	7,8	-	-
Czech republic[c]	-	-	rape[b]	0,1
France	sugarbeet[b]	4,6	rape[b]	15,3
Germany	wheat[b]	7,7	rape[b]	81,8
Hungary	sugarbeet[c]	0,2	-	-
India	sugarcane[b]	4,7	-	-
Italy	-	-	rape[b]	8,1
Korea, republic	-	-	rape[c]	0,5
Latvia	-	-	rape[c]	0,2
Lithuania	sugarbeet	0,0	rape[c]	0,1
Poland	sugarbeet[c]	1,6	rape[b]	0,6
Slovakia	-	-	rape[c]	0,5
Spain	wheat[b]	5,2	rape[c]	6,7
Sweden	wheat[b]	6,6	rape[c]	0,3
Switzerland	sugarbeet	0,0	rape[c]	0,2
United Kingdom	sugarbeet[b]	2,1	rape[b]	1,6
United States	maize[b]	352,6	soy[b]	13,6
Total	-	741,9	-	133,4

a) Source: [IEA, 2007], values are increased by 10% to convert heating values LHV to HHV.
b) Source: [Dufey, 2006]
c) Assumed feedstock

Table G.6: Feedstock and consumption of fuelwood and charcoal in 2005 of 25 countries; A-K

Country	coniferous fuelwood		non-coniferous fuelwood		wood charcoal	
	feedstock[a]	consumption $PJ\ HHV/yr$	feedstock[b]	consumption $PJ\ HHV/yr$	feedstock[c]	consumption $PJ\ HHV/yr$
Argentina	pine	0	eucalyptus	44	eucalyptus	12
Australia	pine	0	eucalyptus	56	eucalyptus	1
Austria	pine	22	poplar	15	poplar	0
Belgium	pine	1	poplar	6	poplar	0
Brazil	pine	138	eucalyptus	1240	eucalyptus	296
Burkina Faso	pine	0	eucalyptus	105	eucalyptus	16
Canada	pine	4	poplar	23	poplar	0
Chile	pine	20	eucalyptus	111	eucalyptus	8
China	pine	839	poplar	1234	poplar	56
Colombia	pine	23	eucalyptus	80	eucalyptus	15
Cuba	pine	0	eucalyptus	18	eucalyptus	2
Czech Republic	pine	7	poplar	5	poplar	0
Egypt	pine	0	eucalyptus	169	eucalyptus	40
Ethiopia	pine	66	eucalyptus	879	eucalyptus	103
France	pine	35	poplar	314	poplar	3
Germany	pine	41	poplar	19	poplar	5
Guatemala	pine	101	eucalyptus	62	eucalyptus	0
Hungary	pine	1	poplar	30	poplar	0[d]
India	pine	92	eucalyptus	2963	eucalyptus	54
Indonesia	pine	0	eucalyptus	737	eucalyptus	0[d]
Iran	pine	0	poplar	0	pine	0
Italy	pine	4	eucalyptus	53	pine	2
Japan	pine	0	eucalyptus	1	eucalyptus	6
Kazakhstan	pine	2	poplar	0	poplar	0
Korea, Republic of	pine	9	poplar	16	poplar	4
Sub-total A-K		1404		8183		623
Total A-Z		1934		11300		913

a) All coniferous fuelwood is treated as wood from pine trees.
b) Non-coniferous fuelwood is treated as wood from eucalyptus trees for tropical and subtropical countries, and as poplar for temperate and boreal countries. Climates of countries A-K are listed in appendix H table H.8.
c) Wood charcoal is treated as charcoal from the most water efficient fuelwood species.
d) These countries report an export which is higher than their production and import, this would result in a negative consumption. Consumption is therefore set to 0.

Table G.7: Feedstock and consumption of fuelwood and charcoal in 2005 of 25 countries; L-Z

Country	coniferous fuelwood		non-coniferous fuelwood		wood charcoal	
	feedstock	consumption[a] $PJ\ HHV/yr$	feedstock	consumption[b] $PJ\ HHV/yr$	feedstock	consumption[c] $PJ\ HHV/yr$
Latvia	pine	7	poplar	2	poplar	0
Lithuania	pine	5	poplar	6	poplar	0
Malaysia	pine	0	eucalyptus	31	eucalyptus	0[d]
Mali	pine	0	eucalyptus	50	eucalyptus	4
Mexico	pine	115	eucalyptus	269	eucalyptus	11
Netherlands	pine	1	poplar	2	poplar	1
New Zealand	pine	0	eucalyptus	0	pine	0
Nigeria	pine	0	eucalyptus	613	eucalyptus	108
Pakistan	pine	11	eucalyptus	254	eucalyptus	2
Philippines	pine	0	eucalyptus	130	eucalyptus	6
Poland	pine	17	poplar	17	poplar	2
Russian Federation	pine	187	poplar	283	poplar	2
Slovakia	pine	1	poplar	1	poplar	1
South Africa	pine	0	eucalyptus	120	eucalyptus	5
Spain	pine	5	eucalyptus	17	eucalyptus	1
Sudan	pine	0	eucalyptus	177	pine	27
Sweden	pine	39	poplar	20	poplar	1
Switzerland	pine	5	poplar	8	poplar	1
Tanzania	pine	0	eucalyptus	217	eucalyptus	43
Thailand	pine	0	eucalyptus	199	eucalyptus	41
Turkey	pine	19	poplar	31	poplar	0
Ukraine	pine	33	poplar	49	poplar	0[d]
United Kingdom	pine	1	poplar	2	poplar	2
United States	pine	83	poplar	355	poplar	30
Viet Nam	pine	0	eucalyptus	264	eucalyptus	3
Sub-total L-Z		530		3117		300
Total A-Z		1934		11300		913

a) All coniferous fuelwood is treated as wood from pine trees.
b) Non-coniferous fuelwood is treated as wood from eucalyptus trees for tropical and subtropical countries, and as poplar for temperate and boreal countries. Climates of countries L-Z are listed in appendix H table H.9.
c) Wood charcoal is treated as charcoal from the most water efficient fuelwood species.
d) These countries report an export which is higher than their production and import, this would result in a negative consumption. Consumption is therefore set to 0.

Appendix H

Agriculture - results appendix

H.1 Total biological yield

Table H.1: Average production of crop categories 1-3 in the period 1997-2001 for 25 countries expressed total biological yield; A-K ($DM\ Mton/yr$)

Country	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Argentina	28,2	30,4	10,3	-	8,3	44,5	0	-
Australia	42,5	0,7	5,5	-	16,8	0,2	3,9	-
Austria	2,6	3,3	-	0,9	-	0,1	0,3	-
Belgium	3	0,8	-	1,9	-	-	0	-
Brazil	4,6	63,6	2,2	-	152	73,8	0,1	0,1
Burkina Faso	-	0,8	3,7	-	0,2	0	-	-
Canada	46,3	15,4	-	0,2	-	5,8	16,2	-
Chile	3	1,5	-	1	-	-	0,1	-
China	204	222	10,7	3,6	35,6	34,5	23,4	0,3
Colombia	0,1	1,9	0,7	-	15,2	0,1	-	0,6
Cuba	-	0,4	0	-	15,7	-	-	-
Czech Republic	7,6	0,6	-	1	-	0	1,8	-
Egypt	11,8	11,7	2,9	0,7	6,7	0,1	-	-
Ethiopia	2,3	5,3	4,7	0	0,9	0,1	0	-
France	67,8	30,2	1,2	10	-	0,6	8,3	-
Germany	39,3	6,1	0	8,4	-	0	8,5	-
Guatemala	0	1,9	0,2	-	7,8	0,1	-	0,1
Hungary	8,2	12,5	0	0,9	-	0,1	0,4	-
India	133	22,2	25,9	-	129	14,7	12,5	-
Indonesia	-	17,8	-	-	11,5	2,7	-	8,5
Iran	18,2	2	-	1,5	1,1	0,3	-	-
Italy	13,9	18,8	0,6	4,1	-	2,3	0,1	-
Japan	1,2	0	-	1,2	0,7	0,5	0	-
Kazakhstan	17,7	0,4	0	0,1	-	0	0	-
Korea, Republic of	0	0,1	0	-	-	0,3	0	-
Sub-total A-K	656	470	69	36	401	181	76	10
Total A-Z	1030	1040	175	74	513	356	85	25
World total	1120	1140	193	81	566	369	88	28

When a crop reports 0 $DM\ Mton/yr$ it refers to an average production of less than $0,05$ $DM\ Mton/yr$. When a crop reports $-$ it refers to no production at all.

Table H.2: Average production of crop categories 1-3 in the period 1997-2001 for 25 countries expressed total biological yield; L-Z ($DM\ Mton/yr$)

Country	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Latvia	0,8	-	-	0,1	-	0	0	-
Lithuania	2	-	-	0,3	-	-	0,2	-
Malaysia	-	0,1	-	-	0,7	0	-	13,5
Mali	0	0,7	1,9	-	0,1	-	-	-
Mexico	6,3	34,6	19,8	0	20,9	0,3	0	0
Netherlands	1,9	0,3	-	2,1	-	-	0	-
New Zealand	0,6	0,3	-	-	-	-	0	-
Nigeria	0,1	9,3	24,2	-	0,3	0,9	-	1,2
Pakistan	35,2	3,1	0,7	0	21,6	0	0,7	-
Philippines	-	8,2	0	-	11,7	0	-	0,1
Poland	16,8	1,4	-	4,3	-	0	2,2	-
Russian Federation	69,4	2,6	0,1	4,4	-	0,7	0,3	-
Slovakia	3	1,3	0	0,4	-	0	0,4	-
South Africa	4,2	17	1,1	-	10	0,4	-	-
Spain	10,4	8,1	0,1	2,6	0	0	0,1	-
Sudan	0,7	0,1	10,7	0	2,5	-	-	-
Sweden	4	-	-	0,8	-	-	0,3	-
Switzerland	1,1	0,4	-	0,4	-	0	0,1	-
Tanzania	0,2	5,1	2	-	0,6	0	-	0
Thailand	0	8,2	0,5	-	23,1	0,7	-	0,7
Turkey	36,9	4,2	-	5,7	-	0,1	0	-
Ukraine	29,6	6,4	0	4,8	-	0,1	0,2	-
United Kingdom	27,8	-	-	3,1	-	-	3,3	-
United States	118	459	45,3	8,9	14,1	172	1,6	-
Viet Nam	-	3,5	0	-	6,6	0,3	-	-
Sub-total L-Z	370	574	106	38	112	176	10	15
Total A-Z	1030	1040	175	74	513	356	85	25
World total	1120	1140	193	81	566	369	88	28

When a crop reports 0 $DM\ Mton/yr$ it refers to an average production of less than $0,05\ DM\ Mton/yr$. When a crop reports $-$ it refers to no production at all.

Table H.3: Current total biological yield of crop categories 1-3 for 25 countries; A-K (*DM ton/ha*)

Country	wheat[b]	maize[b]	sorghum[b]	sugarbeet[b]	sugarcane[a]	soy[b]	rape[b]	oil palm[a]
Argentina	4,6	10,2	14,5	-	-[c]	5,4	3,2	-
Australia	3,7	9,6	9,1	-	-[c]	4,2	3,0	-
Austria	9,6	18,1	-	20,0	-	5,3	6,0	-
Belgium	15,1	21,2	-	20,1	-	-	7,6	-
Brazil	3,3	5,4	5,7	-	30,9	5,6	3,5	13,3
Burkina Faso	-	3,1	2,7	-	-[c]	2,5	-	-
Canada	4,3	13,5	-	14,8	-	5,6	3,3	-
Chile	7,6	17,0	-	20,2	-	-	6,0	-
China	7,3	9,0	11,3	8,4	30,8	4,0	3,4	19,2
Colombia	3,9	3,5	10,3	-	38,5	4,9	-	23,9
Cuba	-	3,4	2,5	-	14,7	-	-	-
Czech Republic	8,4	12,3	-	14,0	-	3,2	6,1	-
Egypt	11,6	13,8	18,3	14,8	52,5	-[c]	-	-
Ethiopia	2,4	3,2	4,0	-	44,0	8,0	1,7	-
France	13,3	16,7	19,9	22,6	-	6,0	7,2	-
Germany	14,0	16,5	-	17,7	-	4,5	7,9	-
Guatemala	3,8	3,2	3,9	-	44,4	6,9	-	24,9
Hungary	7,5	11,1	6,7	12,9	-	4,7	3,8	-
India	5,0	3,4	2,6	-	31,1	2,3	2,1	-
Indonesia	-	5,1	-	-	30,0	2,8	-	23,2
Iran	3,3	11,9	-	8,6	37,6	3,8	-	-
Italy	5,9	18,0	19,7	14,7	-	8,4	2,3	-
Japan	6,8	4,6	-	17,7	30,0	4,1	3,7	-
Kazakhstan	1,8	-[c]	-[c]	-[c]	-	-[c]	-[c]	-
Korea, Republic of	6,4	7,6	4,6	-	-	3,3	3,3	-

a) Yields of perennial crops refer to the yield per year.
b) Yields of annual crops refer to the yield per cultivation period.
c) These yields are excluded as their calculation does not meet the requirements set in the water section.

Table H.4: Current total biological yield of crop categories 1-3 for 25 countries; L-Z (*DM ton/ha*)

Country	wheat[b]	maize[b]	sorghum[b]	sugarbeet[b]	sugarcane[a]	soy[b]	rape[b]	oil palm[a]
Latvia	4,9	-	-	-	-	2,7	3,2	-
Lithuania	5,6	-	-	9,8	-	-	3,5	-
Malaysia	-	4,3	-	-	33,4	0,8	-	24,6
Mali	4,1	2,8	2,9	-	-	-[d]	-	-
Mexico	8,8	4,6	10,3	12,7	33,4	3,6	2,8	19,3
Netherlands	15,1	16,2	-	18,2	-	-	7,8	-
New Zealand	11,9	19,2	-	-	-	-	4,4	-
Nigeria	3,4	2,6	3,6	-	-[c]	1,8	-	-[c]
Pakistan	4,3	3,2	2,0	8,6	21,0	2,8	2,2	-
Philippines	-	3,2	-	-	32,8	2,8	-	17,6
Poland	6,5	11,0	-	11,8	-	0,5	5,0	-
Russian Federation	3,2	4,0	-	5,8	-	2,0	2,0	-
Slovakia	7,6	9,8	7,3	11,8	-	3,5	4,6	-
South Africa	4,5	4,6	8,7	-	28,7	3,7	-	-
Spain	4,8	17,8	14,9	19,2	-[c]	5,3	3,8	-
Sudan	3,9	1,3	2,0	-	-[c]	-	-	-
Sweden	11,1	-	-	14,3	-	-	5,2	-
Switzerland	11,2	17,8	-	21,4	-	7,0	7,0	-
Tanzania	2,5	1,7	3,1	-	40,6	0,8	-	18,0
Thailand	1,2	6,6	5,3	-	25,1	3,3	-	21,3
Turkey	3,9	7,8	-	-[c]	-	6,2	-[c]	-
Ukraine	4,9	5,5	2,8	5,5	-	-[c]	2,3	-
United Kingdom	14,4	-	-	17,0	-	-	6,9	-
United States	5,3	15,9	13,4	15,6	35,4	5,9	3,5	-
Viet Nam	-	5,0	-	-	22,2	2,7	-	-

a) Yields of perennial crops refer to the yield per year.
b) Yields of annual crops refer to the yield per cultivation period.
c) These yields are excluded as their calculation does not meet the requirements set in the water section.
d) The data reports inconsistent/abarrant data for this crop.

Table H.5: Current total biological yield of trees (*DM ton/ha*)

Country	eucalyptus[a]	pine[a]	poplar[a]
Argentina	21,3	16,3	16,7
Australia	12,4	8,5	-
Belgium	-	8,3	10,0
Brazil	30,0	21,7	13,3
Chile	17,0	16,0	23,3
China	3,4	4,5	7,4
France	-	6,2	-
India	6,7	2,7	15,0
Indonesia	12,7	5,3	-
Iran	4,7	-	5,7
Italy	10,7	14,0	12,3
Lithuania	-	4,3	-
Netherlands	-	5,0	9,3
New Zealand	-	12,3	-
Philippines	-	8,3	-
Poland	-	5,1	7,6
Slovakia	-	3,0	4,9
South Africa	15,3	8,9	-
Sudan	8,7	-	-
Ukraine	-	-	5,8
United Kingdom	-	6,0	-
United States	-	3,9	-
Viet Nam	5,7	2,7	-

a) Yields of perennial crops refer to the yield per year.

Table H.6: HEI system total biological yield of crop categories 1-3 for 25 countries; A-K (*DM ton/ha*)

Country	wheat[b]	maize[b]	sorghum[b]	sugarbeet[b]	sugarcane[a]	soy[b]	rape[b]	oil palm[a]
Argentina	14,4	27,4	34,8	-[c]	-[d]	9,9	13,1	-[c]
Australia	13,5	25,7	33,5	-[c]	-[d]	8,7	11,8	-[c]
Austria	22,6	20,5	-	10,8	-	8,8	13,0	-
Belgium	19,3	7,6	-	9,2	-	-	10,2	-
Brazil	8,8	20,3	28,3	-[c]	45,8	6,9	9,3	29,7
Burkina Faso	-	22,3	28,8	-	-[d]	7,0	-	-[c]
Canada	13,3	18,7	-	10,0	-	8,4	10,4	-
Chile	17,5	22,0	-[c]	16,5	-	-[c]	11,8	-
China	16,8	23,7	28,8	12,0	51,2	9,2	12,0	26,4
Colombia	14,9	20,4	28,4	-	44,5	6,5	-[c]	28,9
Cuba	-	19,7	17,7	-	55,9	-[c]	-	-[c]
Czech Republic	22,4	19,7	-	10,3	-	6,8	12,9	-
Egypt	14,1	28,3	33,9	15,7	47,1	-[d]	-[c]	-[c]
Ethiopia	10,9	22,9	29,5	-	56,6	7,7	12,2	-[c]
France	19,5	22,3	-	11,9	-	8,5	13,0	-
Germany	23,1	20,7	-	10,5	-	7,7	13,1	-
Guatemala	9,5	13,9	14,3	-	52,5	4,7	-[c]	36,0
Hungary	20,7	21,6	22,7	12,0	-	9,3	13,7	-
India	9,7	23,8	31,1	-[c]	53,4	7,9	10,9	-[c]
Indonesia	-	19,8	-[c]	-	43,4	7,1	-	32,1
Iran	17,2	27,6	-[c]	13,0	46,9	9,3	-[c]	-[c]
Italy	19,8	26,3	28,7	14,4	-	9,9	12,3	-
Japan	18,7	19,9	-[c]	9,8	28,7	7,0	11,5	-
Kazakhstan	16,4	-[d]	-[d]	-[d]	-	-[d]	-[d]	-
Korea, Republic of	21,8	24,9	14,3	-[c]	-	8,1	11,0	-

a) Yields of perennial crops refer to the yield per year.
b) Yields of annual crops refer to the yield per cultivation period.
c) These yields are excluded as the current situation does not report yields for this crop.
d) These yields are excluded as the yields of the current situation are excluded.

Table H.7: HEI system total biological yield of crop categories 1-3 for 25 countries; L-Z ($DM\ ton/ha$)

Country	wheat^b	maize^b	sorghum^b	sugarbeet^b	sugarcane^a	soy^b	rape^b	oil palm^a
Latvia	18,7	-	-	-	-	-	11,7	-
Lithuania	20,3	-	-	8,2	-	-	12,1	-
Malaysia	-	-	-	-	40,1	-	-	32,9
Mali	8,6	22,2	29,2	-	-^{d}	-^{d}	-^{c}	-^{c}
Mexico	11,9	24,2	31,1	12,7	53,1	8,3	12,0	34,1
Netherlands	22,9	7,8	-	9,6	-	-^{d}	11,4	-
New Zealand	15,9	20,1	-	-^{c}	-	-	12,5	-
Nigeria	9,4	21,6	29,0	-	-^{d}	7,2	-	-^{d}
Pakistan	12,5	26,7	35,2	12,5	49,2	8,3	11,6	-^{c}
Philippines	-^{c}	17,5	-^{c}	-	52,8	5,9	-^{c}	35,0
Poland	23,0	8,1	-	10,4	-	6,5	13,2	-
Russian Federation	14,8	19,1	-^{d}	10,0	-	8,3	11,3	-
Slovakia	22,1	19,8	-	10,8	-	8,0	13,3	-
South Africa	13,6	26,3	32,5	-^{c}	48,5	9,0	-^{c}	-^{c}
Spain	17,1	26,1	30,7	14,5	-^{d}	9,9	12,7	-
Sudan	8,0	23,1	30,4	-	-^{d}	-^{c}	-^{c}	-^{c}
Sweden	18,4	-	-	8,8	-	-	11,3	-
Switzerland	22,5	19,0	-	9,8	-	6,0	12,3	-
Tanzania	9,5	22,0	28,7	-	56,1	7,5	-^{c}	35,2
Thailand	6,9	18,0	22,6	-	48,9	5,9	-^{c}	32,4
Turkey	23,7	27,6	-^{c}	-^{d}	-^{c}	10,5	-^{d}	-
Ukraine	21,5	20,9	28,3	11,2	-	-^{c}	13,4	-
United Kingdom	19,3	-	-	9,5	-	-	11,3	-
United States	19,0	25,0	33,2	12,8	44,5	9,6	13,1	-^{c}
Viet Nam	-^{c}	21,8	-^{c}	-^{c}	49,5	6,8	-^{c}	-^{c}

a) Yields of perennial crops refer to the yield per year.
b) Yields of annual crops refer to the yield per cultivation period.
c) These yields are excluded as the current situation does not report yields.
d) These yields are excluded as yields of the current situation are excluded.

H.2 Crop location and start of the cultivation period

Table H.8: Capital and climate of 25 countries; A-K

Country	capital[a]	latitude[ab]	longitude[ac]	climate	sub-group
Argentina	Buenos Aires	-34,4	-58,4	sub-tropic	summer rain
Australia	Canberra	-35,2	149,1	sub-tropic	summer rain
Austria	Vienna	48,3	16,3	temperate	sub-continental
Belgium	Brussels	50,5	4,2	temperate	oceanic
Brazil	Brasilia	-15,5	-47,6	tropics	-
Burkina Faso	Ouagadougou	12,3	-1,5	tropics	-
Canada	Ottawa	45,3	-75,7	temperate	sub-continental
Chile	Santiago	-33,3	-70,4	sub-tropic	winter rain
China	Beijing	39,6	116,2	temperate	sub-continental
Colombia	Bogota	4,4	-74,1	sub-tropic	summer rain
Cuba	Havana	23,1	-82,3	tropics	-
Czech Republic	Praha	50,09	14,43	temperate	sub-continental
Egypt	Cairo	30,0	31,2	sub-tropic	winter rain
Ethiopia	Addis ababa	9,0	38,4	sub-tropic	summer rain
France	Paris	48,5	2,2	temperate	oceanic
Germany	Berlin	52,3	13,2	temperate	oceanic
Guatemala	Guatemala	14,75	-90,58	sub-tropic	summer rain
Hungary	Budapest	47,5	19,1	temperate	sub-continental
India	New Delhi	28,4	77,1	sub-tropic	summer rain
Indonesia	Jakarta	-6,1	106,5	tropics	-
Iran	Tehran	35,4	51,3	temperate	sub-continental
Italy	Rome	41,5	12,3	sub-tropic	winter rain
Japan	Tokyo	35,4	139,5	sub-tropic	summer rain
Kazakhstan	Astana	51,1	71,3	temperate	continental
Korea, Republic of	Seoul	37,55	127,0	temperate	sub-continental

a) Source: [CIA, 2007]
b) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
c) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.9: Capital and climate of 25 countries; L-Z

Country	capital[a]	latitude[ab]	longitude[ac]	climate	sub-group
Latvia	Riga	57,0	24,1	temperate	sub-continental
Lithuania	Vilnius	54,4	25,2	temperate	sub-continental
Malaysia	Kuala Lumpur	3,1	101,4	tropics	-
Mali	Bamako	12,4	-8,0	tropics	-
Mexico	Mexico	19,3	-99,1	sub-tropic	summer rain
Netherlands	Amsterdam	52,2	4,5	temperate	oceanic
New Zealand	Wellington	-41,3	174,5	sub-tropic	winter rain
Nigeria	Abuja	9,1	7,1	tropics	-
Pakistan	Islamabad	22,4	73,1	tropics	-
Philippines	Manila	14,4	121,0	tropics	-
Poland	Warsaw	52,2	21,0	temperate	sub-continental
Russian Federation	Moscow	55,5	37,4	temperate	sub-continental
Slovakia	Bratislava	48,1	17,1	temperate	sub-continental
South Africa	Pretoria	-25,4	28,1	sub-tropic	summer rain
Spain	Madrid	40,2	-3,4	sub-tropic	winter rain
Sudan	Khartoum	15,4	32,3	tropics	-
Sweden	Stockholm	59,2	18,0	temperate	sub-continental
Switzerland	Bern	46,6	7,5	temperate	oceanic
Tanzania	Dar es Salaam	-6,5	39,2	tropics	-
Thailand	Bangkok	13,5	100,3	tropics	-
Turkey	Akara	39,6	32,5	temperate	sub-continental
Ukraine	Kiev	50,3	30,3	temperate	sub-continental
United Kingdom	London	51,3	-0,1	temperate	oceanic
United States	Washington	38,5	-77,0	temperate	sub-continental
Viet Nam	Hanoi	21,0	105,5	sub-tropic	summer rain

a) Source: [CIA, 2007]
b) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
c) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.10: Location and start of wheat cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina[a]	-34,58	-58,58	sub-tropic	summer rain	135 (May)
Australia[a]	-33,75	151,25	sub-tropic	summer rain	135 (May)
Austria[b]	48,75	16,75	temperate	sub-continental	166 (Jun)
Belgium[c]	50,75	4,25	temperate	oceanic	74 (Mar)
Brazil[a]	-25,08	-49,58	sub-tropic	summer rain	105 (Apr)
Burkina Faso	-	-	-	-	-
Canada[a]	52,58	-106,75	temperate	continental	135 (May)
Chile[b]	-35,75	-71,92	sub-tropic	winter rain	105 (Apr)
China[a]	36,58	118,92	temperate	sub-continental	258 (Sep)
-idem-[b]	44,25	122,08	temperate	continental	196 (Jul)
-idem-[b]	30,25	106,08	sub-tropic	summer rain	74 (Mar)
Colombia[c]	4,58	-74,25	sub-tropic	summer rain	46 (Feb)
Cuba	-	-	-	-	-
Czech Republic[a]	50,25	14,58	temperate	sub-continental	258 (Sep)
Egypt[b]	31,08	31,42	sub-tropic	winter rain	1 (Jan)
Ethiopia[b]	9,08	38,08	sub-tropic	summer rain	74 (Mar)
France[a]	48,08	2,08	temperate	oceanic	288 (Oct)
Germany[a]	48,25	11,75	temperate	oceanic	288 (Oct)
Guatemala[c]	14,75	-90,58	sub-tropic	summer rain	135 (May)
Hungary[b]	47,42	20,25	temperate	sub-continental	258 (Sep)
India[a]	27,08	81,08	sub-tropic	summer rain	288 (Oct)
-idem-[b]	24,75	76,42	sub-tropic	summer rain	196 (Jul)
Indonesia	-	-	-	-	-
Iran[b]	34,42	47,08	temperate	sub-continental	288 (Oct)
Italy[a]	41,25	16,58	sub-tropic	winter rain	288 (Oct)
-idem-[b]	37,75	14,25	sub-tropic	winter rain	288 (Oct)
-idem-[b]	45,42	10,92	temperate	sub-continental	74 (Mar)
Japan[b]	43,75	142,58	temperate	sub-continental	135 (May)
Kazakhstan[b]	53,75	69,25	temperate	continental	135 (May)
Korea, Republic of[c]	37,75	127,08	temperate	sub-continental	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.11: Location and start of wheat cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia[c]	57,08	24,25	temperate	sub-continental	105 (Apr)
Lithuania[b]	55,75	22,42	temperate	sub-continental	105 (Apr)
Malaysia	-	-	-	-	-
Mali[c]	12,58	-8,08	tropics	-	166 (Jun)
Mexico[a]	29,25	-111,08	sub-tropic	summer rain	288 (Oct)
Netherlands[c]	52,42	4,75	temperate	oceanic	105 (Apr)
New Zealand[c]	-41,25	174,75	sub-tropic	winter rain	1 (Jan)
Nigeria[c]	9,42	7,08	tropics	-	135 (May)
Pakistan[a]	31,75	74,42	sub-tropic	summer rain	288 (Oct)
-idem-[b]	33,25	72,08	sub-tropic	summer rain	349 (Dec)
-idem-[bc]	27,75	68,25	sub-tropic	summer rain	166 (Jun)
Philippines	-	-	-	-	-
Poland[a]	50,92	23,42	temperate	sub-continental	258 (Sep)
Russian Federation[b]	55,92	49,25	temperate	sub continental	105 (Apr)
Slovakia[a]	48,25	17,25	temperate	sub-continental	105 (Apr)
South Africa[a]	-33,75	18,58	sub-tropic	winter rain	135 (May)
Spain[a]	41,75	-4,75	temperate	oceanic	319 (Nov)
Sudan[b]	13,08	33,92	tropics	-	166 (Jun)
Sweden[a]	55,75	12,08	temperate	oceanic	258 (Sep)
Switzerland[c]	46,75	7,58	temperate	oceanic	105 (Apr)
Tanzania[c]	-6,25	39,25	tropics	-	319 (Nov)
Thailand[b]	16,58	100,58	tropics	-	135 (May)
Turkey[b]	39,75	31,25	temperate	sub-continental	288 (Oct)
Ukraine[a]	47,08	32,25	temperate	sub-continental	135 (May)
United Kingdom[a]	51,58	-0,08	temperate	oceanic	288 (Oct)
United States[a]	39,25	-95,75	temperate	sub-continental	258 (Sep)
-idem-[b]	46,92	-98,58	temperate	continental	105 (Apr)
-idem-[b]	30,75	-97,58	sub-tropic	summer rain	258 (Sep)
Viet Nam	-	-	-	-	-

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.12: Location and start of maize cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina[a]	-34,58	-58,58	sub-tropic	summer rain	258 (Sep)
Australia[c]	-34,92	149,25	sub-tropic	summer rain	105 (Apr)
Austria[b]	48,75	16,75	temperate	sub-continental	166 (Jun)
Belgium[c]	50,75	4,25	temperate	Oceanic	74 (Mar)
Brazil[a]	-25,08	-49,58	sub-tropic	summer rain	288 (Oct)
Burkina Faso	12,58	-1,58	tropics	-	166 (Jun)
Canada[a]	43,25	-81,25	temperate	sub-continental	135 (May)
Chile[b]	-35,75	-71,92	sub-tropic	winter rain	105 (Apr)
China[a]	36,58	118,92	temperate	sub-continental	105 (Apr)
-idem-[b]	44,25	122,08	temperate	continental	196 (Jul)
-idem-[b]	30,25	106,08	sub-tropic	summer rain	74 (Mar)
Colombia[b]	3,92	-75,25	tropics	-	258 (Sep)
Cuba[c]	23,08	-82,58	tropics	-	135 (May)
Czech Republic[a]	50,25	14,58	temperate	Sub-continental	135 (May)
Egypt[b]	31,08	31,42	sub-tropic	winter rain	1 (Jan)
Ethiopia[b]	9,58	39,08	sub-tropic	summer rain	105 (Apr)
France[a]	45,08	-0,75	sub-tropic	Winter-rain	105 (Apr)
Germany[c]	52,58	13,25	temperate	Oceanic	105 (Apr)
Guatemala[c]	14,75	-90,58	sub-tropic	summer rain	135 (May)
Hungary[b]	46,92	21,25	temperate	sub-continental	105 (Apr)
India[a]	27,08	81,08	sub-tropic	summer rain	166 (Jun)
Indonesia[b]	-4,42	105,25	tropics	-	1 (Jan)
Iran[c]	35,58	51,42	temperate	sub-continental	288 (Oct)
Italy[a]	45,58	12,42	temperate	sub-continental	105 (Apr)
Japan[b]	43,75	142,58	temperate	sub-continental	135 (May)
Kazakhstan[b]	42,75	69,25	temperate	sub-continental	74 (Mar)
Korea, Republic of[c]	37,75	127,08	temperate	sub-continental	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.13: Location and start of maize cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia[c]	57,08	24,25	temperate	sub-continental	105 (Apr)
Lithuania[c]	-	-	-	-	-
Malaysia[c]	3,25	101,58	tropics	-	1 (Jan)
Mali[b]	13,92	-6,08	tropics	-	166 (Jun)
Mexico[a]	20,92	-103,42	sub-tropic	summer rain	135 (May)
-idem-[b]	21,25	-98,58	tropics	-	105 (Apr)
-idem-[b]	17,75	-94,58	tropics	-	166 (Jun)
Netherlands[c]	52,42	4,75	temperate	oceanic	105 (Apr)
New Zealand[c]	-41,25	174,75	sub-tropic	winter rain	1 (Jan)
Nigeria[b]	12,08	9,25	tropics	-	196 (Jul)
Pakistan[b]	31,58	73,08	sub-tropic	summer rain	196 (Jul)
Philippines[c]	14,58	121,08	tropics	-	135 (May)
Poland[c]	52,42	21,08	temperate	sub-continental	166 (Jun)
Russian Federation[a]	44,25	39,25	temperate	subcontinental	74 (Mar)
Slovakia[a]	48,25	17,25	temperate	sub-continental	105 (Apr)
South Africa[a]	-28,75	26,08	sub-tropic	summer rain	288 (Oct)
Spain[a]	41,75	-4,75	temperate	oceanic	74 (Mar)
Sudan[b]	13,92	35,92	tropics	-	166 (Jun)
Sweden	-	-	-	-	-
Switzerland[c]	46,75	7,58	temperate	oceanic	105 (Apr)
Tanzania[b]	-8,25	33,75	summer rain	summer rain	319 (Nov)
Thailand[b]	16,92	100,58	tropics	-	135 (May)
-idem-[b]	15,25	103,58	tropics	-	105 (Apr)
Turkey[b]	41,75	35,08	temperate	oceanic	74 (Mar)
Ukraine[a]	48,58	35,08	temperate	sub-continental	135 (May)
United Kingdom	-	-	-	-	-
United States[a]	41,92	-93,92	temperate	sub-continental	105 (Apr)
Viet Nam[c]	21,25	105,58	sub-tropic	summer rain	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.14: Location and start of sorghum cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina[a]	-31,75	-64,08	sub-tropic	summer rain	288 (Oct)
Australia[a]	-27,25	153,08	sub-tropic	summer rain	288 (Oct)
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil[bc]	-15,08	-47,92	tropics	-	288 (Oct)
Burkina Faso[b]	12,92	-1,92	tropics	-	166 (Jun)
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China[a]	42,25	123,08	temperate	continental	196 (Jul)
Colombia[b]	4,08	-75,58	sub-tropic	winter rain	258 (Sep)
Cuba[c]	23,08	-82,58	Tropics	-	135 (May)
Czech Republic	-	-	-	-	-
Egypt[b]	31,08	31,42	sub-tropic	winter rain	1 (Jan)
Ethiopia[b]	9,08	38,92	sub-tropic	summer rain	74 (Mar)
France[c]	48,75	2,25	Oceanic	oceanic	74 (Mar)
Germany	-	-	-	-	-
Guatemala[c]	14,75	-90,58	sub-tropic	summer rain	135 (May)
Hungary[b]	47,75	19,08	temperate	sub-continental	105 (Apr)
India[b]	19,25	72,75	tropics	-	166 (Jun)
-idem-[b]	14,25	78,08	tropics	-	196 (Jul)
-idem-[b]	23,25	77,08	sub-tropic	summer rain	166 (Jun)
Indonesia	-	-	-	-	-
Iran	-	-	-	-	-
Italy[b]	45,25	11,75	temperate	sub-continental	74 (Mar)
Japan	-	-	-	-	-
Kazakhstan[c]	51,25	71,42	temperate	continental	135 (May)
Korea, Republic of[c]	37,75	127,08	temperate	sub-continental	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.15: Location and start of sorghum cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	-	-	-	-	-
Mali[b]	14,08	-6,92	tropics	-	196 (Jul)
Mexico[a]	23,92	-99,25	sub-tropic	summer rain	46 (Feb)
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria[b]	12,25	8,42	tropics	-	196 (Jul)
Pakistan[b]	31,58	73,08	sub-tropic	summer rain	196 (Jul)
Philippines	-	-	-	-	-
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia[a]	48,25	17,25	temperate	sub-continental	105 (Apr)
South Africa[b]	-23,58	28,08	sub-tropic	summer rain	15 (Jan)
Spain[c]	40,42	-3,58	sub-tropic	winter rain	288 (Oct)
Sudan[b]	12,25	30,42	tropics	-	166 (Jun)
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania[b]	-5,08	38,58	tropics	-	15 (Jan)
Thailand[b]	16,92	100,58	tropics	-	135 (May)
Turkey	-	-	-	-	-
Ukraine[a]	46,75	32,75	temperate	sub-continental	105 (Apr)
United Kingdom	-	-	-	-	-
United States[a]	37,92	-97,42	temperate	sub-continental	105 (Apr)
Viet Nam[c]	21,25	105,58	sub-tropic	summer rain	46 (Feb)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.16: Location and start of sugarbeet cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina	-	-	-	-	-
Australia	-	-	-	-	-
Austria[b]	48,75	16,75	temperate	sub-continental	166 (Jun)
Belgium[c]	50,75	4,25	temperate	oceanic	74 (Mar)
Brazil	-	-	-	-	-
Burkina Faso	-	-	-	-	-
Canada[c]	45,58	-75,75	temperate	sub-continental	135 (May)
Chile[b]	-35,75	-71,92	sub-tropic	winter rain	105 (Apr)
China[a]	45,92	126,75	temperate	continental	105 (Apr)
Colombia	-	-	-	-	-
Cuba	-	-	-	-	-
Czech Republic[c]	50,25	14,58	temperate	sub-continental	135 (May)
Egypt[b]	31,08	31,42	sub-tropic	winter rain	1 (Jan)
Ethiopia[c]	9,25	38,58	sub-tropic	summer rain	74 (Mar)
France[a]	50,08	2,42	temperate	oceanic	105 (Apr)
Germany[a]	52,58	9,75	temperate	oceanic	105 (Apr)
Guatemala	-	-	-	-	-
Hungary[c]	47,75	19,08	temperate	sub-continental	105 (Apr)
India	-	-	-	-	-
Indonesia	-	-	-	-	-
Iran[b]	34,25	47,08	temperate	sub-continental	288 (Oct)
Italy[b]	45,25	11,75	temperate	sub-continental	105 (Apr)
-idem-[b]	37,75	14,08	sub-tropic	winter rain	288 (Oct)
-idem-[b]	41,08	16,08	sub-tropic	winter rain	258 (Sep)
Japan[b]	43,75	142,58	temperate	sub-continental	135 (May)
Kazakhstan[b]	45,92	79,25	temperate	sub-continental	105 (Apr)
Korea, Republic of	-	-	-	-	-

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.17: Location and start of sugarbeet cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia	57,00	24,1	temperate	sub-continental	105 (Apr)
Lithuania[b]	55,58	23,08	temperate	sub-continental	105 (Apr)
Malaysia	-	-	-	-	-
Mali	-	-	-	-	-
Mexico[c]	19,42	-99,25	sub-tropic	summer rain	166 (Jun)
Netherlands[c]	52,42	4,75	temperate	oceanic	105 (Apr)
New Zealand	-	-	-	-	-
Nigeria	-	-	-	-	-
Pakistan[c]	22,58	73,25	tropics	tropics	166 (Jun)
Philippines	-	-	-	-	-
Poland[a]	50,92	23,42	temperate	sub-continental	105 (Apr)
Russian Federation[b]	52,75	40,42	temperate	sub-continental	196 (Jul)
Slovakia[a]	48,25	17,25	temperate	sub-continental	105 (Apr)
South Africa	-	-	-	-	-
Spain[b]	42,75	-3,58	temperate	oceanic	74 (Mar)
Sudan	-	-	-	-	-
Sweden[c]	59,42	18,08	temperate	sub-continental	105 (Apr)
Switzerland[c]	46,75	7,58	temperate	oceanic	105 (Apr)
Tanzania	-	-	-	-	-
Thailand	-	-	-	-	-
Turkey[b]	39,75	30,75	temperate	sub-continental	135 (May)
Ukraine[a]	49,42	28,58	temperate	sub-continental	105 (Apr)
United Kingdom[a]	52,42	0,25	temperate	oceanic	74 (Mar)
United States[a]	45,42	-93,42	temperate	sub-continental	105 (Apr)
Viet Nam	-	-	-	-	-

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.18: Location and start of sugarcane cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina[a]	-26,92	-65,42	sub-tropic	summer rain	227 (Aug)
Australia[a]	-27,42	151,08	sub-tropic	summer rain	1 (Jan)
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil[a]	-21,75	-48,08	tropics	-	196 (Jul)
Burkina Faso[c]	12,58	-1,58	tropics	-	166 (Jun)
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China[b]	23,08	108,25	sub-tropic	summer rain	46 (Feb)
Colombia[b]	3,92	-75,42	tropics	-	258 (Sep)
Cuba[a]	22,25	-80,08	tropics	-	349 (Dec)
Czech Republic	-	-	-	-	-
Egypt[b]	31,08	31,42	sub-tropic	winter rain	1 (Jan)
Ethiopia[c]	9,25	38,58	sub-tropic	summer rain	74 (Mar)
France	-	-	-	-	-
Germany	-	-	-	-	-
Guatemala[c]	14,75	-90,58	sub-tropic	summer rain	135 (May)
Hungary	-	-	-	-	-
India[b]	27,75	79,75	sub-tropic	summer rain	196 (Jul)
-idem-[b]	11,25	78,58	tropics	-	227 (Aug)
Indonesia[b]	-4,08	105,42	tropics	-	258 (Sep)
Iran[c]	35,58	51,42	temperate	sub-continental	288 (Oct)
Italy	-	-	-	-	-
Japan[b]	43,75	142,58	temperate	sub-continental	135 (May)
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.19: Location and start of sugarcane cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia[c]	3,25	101,58	tropics	-	1 (Jan)
Mali[c]	12,58	-8,08	tropics	-	166 (Jun)
Mexico[a]	19,08	-96,25	tropics	-	166 (Jun)
-idem-[b]	21,75	-98,58	tropics	-	135 (May)
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria[c]	9,42	7,08	tropics	-	135 (May)
Pakistan[a]	31,75	74,42	sub-tropic	summer rain	46 (Feb)
Philippines[c]	14,58	121,08	tropics	-	135 (May)
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa[a]	-29,75	31,08	sub-tropic	summer rain	227 (Aug)
Spain[c]	40,42	-3,58	sub-tropic	winter rain	288 (Oct)
Sudan[b]	12,75	33,58	tropics	-	166 (Jun)
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania[b]	-4,75	38,58	tropics	-	319 (Nov)
Thailand[b]	16,92	100,58	tropics	-	135 (May)
-idem-[b]	15,42	103,42	tropics	-	105 (Apr)
-idem-[b]	8,58	99,58	tropics	-	105 (Apr)
Turkey	-	-	-	-	-
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States[a]	25,92	-80,42	tropics	-	227 (Aug)
Viet Nam[c]	21,25	105,58	sub-tropic	summer rain	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.20: Location and start of soy cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina[bc]	-34,58	-58,58	sub-tropic	summer rain	319 (Nov)
Australia[bc]	-34,92	149,25	sub-tropic	summer rain	105 (Apr)
Austria	48,42	16,42	temperate	sub-continental	135 (May)
Belgium	-	-	-	-	-
Brazil[a]	-20,75	-48,08	tropics	-	319 (Nov)
Burkina Faso[c]	12,58	-1,58	tropics	-	166 (Jun)
Canada[a]	43,25	-81,25	temperate	sub-continental	135 (May)
Chile	-	-	-	-	-
China[b]	45,92	126,75	temperate	continental	105 (Apr)
Colombia[c]	4,58	-74,25	summer rain	summer rain	46 (Feb)
Cuba	-	-	-	-	-
Czech Republic	50,25	14,58	temperate	sub-continental	135 (May)
Egypt[b]	31,08	31,42	sub-tropic	winter rain	1 (Jan)
Ethiopia[c]	9,25	38,58	sub-tropic	summer rain	74 (Mar)
France[c]	48,75	2,25	temperate	oceanic	74 (Mar)
Germany[c]	52,58	13,25	temperate	oceanic	105 (Apr)
Guatemala[c]	14,75	-90,58	sub-tropic	summer rain	135 (May)
Hungary[c]	47,75	19,08	temperate	sub-continental	105 (Apr)
India[b]	24,25	78,92	sub-tropic	summer rain	166 (Jun)
Indonesia[b]	-4,08	105,08	tropics	-	1 (Jan)
Iran[c]	35,58	51,42	temperate	sub-continental	288 (Oct)
Italy[b]	45,25	11,75	temperate	sub-continental	105 (Apr)
Japan[b]	43,75	142,58	temperate	sub-continental	135 (May)
Kazakhstan[c]	51,25	71,42	temperate	continental	135 (May)
Korea, Republic of[c]	37,75	127,08	temperate	sub-continental	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.21: Location and start of soy cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia[c]	57,08	24,25	temperate	sub-continental	105 (Apr)
Lithuania	-	-	-	-	-
Malaysia[c]	3,25	101,58	tropics	-	1 (Jan)
Mali	-	-	-	-	-
Mexico[b]	25,92	-108,58	sub-tropic	summer rain	196 (Jul)
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria[b]	11,92	9,75	tropics	-	196 (Jul)
Pakistan[c]	22,58	73,25	tropics	-	166 (Jun)
Philippines[c]	14,58	121,08	tropics	-	135 (May)
Poland[c]	52,42	21,08	temperate	sub-continental	166 (Jun)
Russian Federation[b]	54,42	48,08	temperate	sub-continental	105 (Apr)
Slovakia[a]	48,25	17,25	temperate	sub-continental	105 (Apr)
South Africa[b]	-32,75	18,92	sub-tropic	winter rain	135 (May)
Spain[c]	40,42	-3,58	sub-tropic	winter rain	288 (Oct)
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland[c]	46,75	7,58	temperate	oceanic	105 (Apr)
Tanzania[c]	-6,25	39,25	tropics	-	319 (Nov)
Thailand[b]	16,92	100,58	tropics	-	135 (May)
Turkey[b]	47,42	36,42	temperate	sub-continental	74 (Mar)
Ukraine[a]	46,75	32,75	temperate	sub-continental	105 (Apr)
United Kingdom	-	-	-	-	-
United States[a]	33,92	-84,42	temperate	sub-continental	135 (May)
Viet Nam[c]	21,25	105,58	sub-tropic	summer rain	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.22: Location and start of rape cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina[b]	-26,42	-65,08	sub-tropic	summer rain	349 (Dec)
Australia[a]	-33,75	151,25	sub-tropic	summer rain	135 (May)
Austria[b]	48,75	16,75	temperate	sub-continental	135 (May)
Belgium[c]	50,75	4,25	temperate	oceanic	74 (Mar)
Brazil[c]	-15,08	-47,92	tropics	-	288 (Oct)
Burkina Faso	-	-	-	-	-
Canada[a]	52,58	-106,75	temperate	continental	135 (May)
Chile[b]	-35,75	-71,92	sub-tropic	winter rain	105 (Apr)
China[b]	32,08	117,42	temperate	sub-continental	319 (Nov)
-idem-[b]	28,25	106,08	temperate	sub-continental	74 (Mar)
Colombia	-	-	-	-	-
Cuba	-	-	-	-	-
Czech Republic[c]	50,25	14,58	temperate	sub-continental	135 (May)
Egypt	-	-	-	-	-
Ethiopia[b]	8,25	38,08	sub-tropic	summer rain	74 (Mar)
France[a]	47,58	5,08	temperate	oceanic	74 (Mar)
Germany[a]	53,75	11,42	temperate	oceanic	105 (Apr)
Guatemala	-	-	-	-	-
Hungary[c]	47,75	19,08	temperate	sub-continental	105 (Apr)
India[b]	26,92	78,08	sub-tropic	summer rain	196 (Jul)
-idem-[b]	23,25	74,08	tropics	-	196 (Jul)
Indonesia	-	-	-	-	-
Iran	-	-	-	-	-
Italy[b]	45,25	11,75	temperate	sub-continental	105 (Apr)
Japan[b]	43,75	142,58	temperate	sub-continental	135 (May)
Kazakhstan	51,25	71,42	temperate	continental	135 (May)
Korea, Republic of[c]	37,75	127,08	temperate	sub-continental	105 (Apr)

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.23: Location and start of rape cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia[c]	57,08	24,25	temperate	sub-continental	135 (May)
Lithuania[b]	55,58	23,08	temperate	sub-continental	105 (Apr)
Malaysia	-	-	-	-	-
Mali	-	-	-	-	-
Mexico[c]	19,42	-99,25	sub-tropic	summer rain	135 (May)
Netherlands[c]	52,42	4,75	temperate	oceanic	105 (Apr)
New Zealand[c]	-41,25	174,75	sub-tropic	winter rain	1 (Jan)
Nigeria	-	-	-	-	-
Pakistan[b]	31,58	73,08	sub-tropic	summer rain	196 (Jul)
Philippines	-	-	-	-	-
Poland[a]	53,75	14,58	temperate	sub-continental	105 (Apr)
Russian Federation[b]	54,42	48,08	temperate	sub-continental	105 (Apr)
Slovakia[a]	48,25	17,25	temperate	sub-continental	105 (Apr)
South Africa	-	-	-	-	-
Spain[c]	40,42	-3,58	sub-tropic	winter rain	288 (Oct)
Sudan	-	-	-	-	-
Sweden[a]	55,75	12,08	temperate	oceanic	105 (Apr)
Switzerland[c]	46,75	7,58	temperate	oceanic	105 (Apr)
Tanzania	-	-	-	-	-
Thailand	-	-	-	-	-
Turkey[c]	39,75	32,75	temperate	sub-continental	74 (Mar)
Ukraine[a]	49,75	25,75	temperate	sub-continental	135 (May)
United Kingdom[a]	51,58	-0,08	temperate	oceanic	74 (Mar)
United States[b]	47,92	-99,92	temperate	continental	166 (Jun)
Viet Nam	-	-	-	-	-

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.24: Location and start of oil palm cultivation in 25 countries; A-K

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Argentina	-	-	-	-	-
Australia	-	-	-	-	-
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil[b]	0,42	-51,25	tropics	-	349 (Dec)
Burkina Faso	-	-	-	-	-
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China[c]	39,75	116,42	temperate	sub-continental	196 (Jul)
Colombia[c]	4,58	-74,25	sub-tropic	summer rain	46 (Feb)
Cuba	-	-	-	-	-
Czech Republic	-	-	-	-	-
Egypt	-	-	-	-	-
Ethiopia	-	-	-	-	-
France	-	-	-	-	-
Germany	-	-	-	-	-
Guatemala[c]	14,75	-90,58	sub-tropic	summer rain	135 (May)
Hungary	-	-	-	-	-
India	-	-	-	-	-
Indonesia[bc]	-4,08	105,08	tropics	-	1 (Jan)
Iran	-	-	-	-	-
Italy	-	-	-	-	-
Japan	-	-	-	-	-
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

Table H.25: Location and start of oil palm cultivation in 25 countries; L-Z

Country	latitude[d]	longitude[e]	climate	sub-group	start cultivation day nr. (month)
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia[bc]	3,25	101,58	tropics	-	1 (Jan)
Mali	-	-	-	-	-
Mexico[c]	19,42	-99,25	sub-tropic	summer rain	166 (Jun)
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria[b]	12,25	9,58	tropics	-	1 (Jan)
Pakistan	-	-	-	-	-
Philippines[c]	14,58	121,08	tropics	-	135 (May)
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa	-	-	-	-	-
Spain	-	-	-	-	-
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania[c]	-6,25	39,25	tropics	-	319 (Nov)
Thailand[b]	16,92	100,58	tropics	-	135 (May)
Turkey	-	-	-	-	-
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	-	-	-	-	-
Viet Nam	-	-	-	-	-

a) Source for start of cultivation and the location of crop cultivation: [USDA, 1994]
b) Start of cultivation determined with climate data of the location of crop cultivation. Source on the location of crop cultivation: [Leff et al., 2004]
c) Start of cultivation determined with climate data of the location of crop cultivation. Location of crop cultivation is the capital
d) Latitude is given in decimal degrees. Positive values refer to degrees North, negative values refer to degrees South.
e) Longitude is given in decimal degrees. Positive values refer to degrees East, negative values refer to degrees West.

H.3 Irrigation

Table H.26: Calculated irrigated area fraction of 25 countries; A-K (%)

Country	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Argentina	1,8	2,1	2,6	0,6	2,7	4,2	2,7	1,2
Australia	3,2	5,2	5,2		4,1	2,2	5,7	
Austria	6,7	5,7	3,8	5,9		1,3	6,4	
Belgium	1,9	1,6	1,3	2,2		1,8	1,5	
Brazil	7,6	3,5	3,3		6,4	5,5	0,6	0,5
Burkina Faso		0,7	0,6		0,1			1,3
Canada	1,0	0,8		1,4		1,5	1,4	
Chile	28,3	26,7	0,4	28,6	0,4	7,3	29,1	
China	22,8	18,4	16,7	15,3	12,8	1,4	20,6	
Columbia	11,6	11,0	11,3		11,3	3,0		11,4
Cuba		17,7	5,5		17,7			
Czech Republic	1,4	2,3		1,4		1,7	1,4	
Egypt	89,6	90,4	90,8	92,5	90,7	1,1		
Ethiopia	1,5	1,5	1,5		1,2	1,7	1,6	
France	11,8	12,0	11,8	11,1		1,4	12,0	
Germany	3,8	3,8	3,4	4,0		2,5	3,9	
Guatemala	3,8	3,8	4,1		3,7	2,0	4,3	
Hungary	5,2	5,4	5,4	5,1		1,4	4,7	
India	42,3	31,4	23,2		40,1	1,2	35,2	
Indonesia		9,9			9,9	1,8		8,6
Iran	31,7	29,1		31,7	31,9	2,3		
Italy	28,9	28,6	29,0	28,8		1,5	25,5	
Japan	28,7	28,7		28,7	28,8	2,4		
Kazakhstan	1,4	10,7	4,8	9,9		1,9	4,3	
Korea, Republic of	28,1	31,9	38,7			3,1	36,6	

Table H.27: Calculated irrigated area fraction of 25 countries; L-Z (%)

Country	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Latvia	0,1	0,0		0,1		2,2	0,1	
Lithuania	0,1	0,1		0,1		1,5	0,1	
Malaysia		5,2	18,8		6,3		1,7	2,8
Mali		4,6	4,5		11,6			4,9
Mexico	45,0	7,9	15,1	94,3	6,4	1,5		3,1
Netherlands	28,5	28,5	1,3	28,0		1,3	31,2	
New Zealand	17,8	17,9					16,3	
Nigeria	1,2	2,3	2,3		0,9	3,8		2,3
Pakistan	55,7	55,2	56,5		56,2	1,1	58,4	
Philippines		11,2			11,2			11,2
Poland	0,6	0,5		0,6		1,7	0,6	
Russian Federation	1,6	2,0	3,9	2,6		1,5	1,7	
Slovakia	9,9	11,5	16,1	9,7		1,1	9,6	
South Africa	5,9	5,8	4,1		5,5	2,9		
Spain	13,9	13,5	12,8	14,0		1,2	13,5	
Sudan	6,6	4,2	7,2		7,5		0,0	
Sweden	9,0	4,6		8,8			9,0	
Switzerland	6,2	6,4	10,7	5,7		2,6	5,4	
Tanzania	1,3	1,1	1,0		1,3	1,9		0,3
Thailand	13,2	19,8	20,1		20,1	1,3		19,5
Turkey	11,6	9,7	25,6	11,4		1,7		
Ukraine	5,4	5,7	10,6	5,4		1,3	4,3	
United Kingdom	1,8	6,1	8,7	1,7		1,8	1,8	
United States	10,5	5,9	12,4	16,1	12,6	1,3	1,7	
Viet Nam	3,1	18,8			19,4	1,4	2,7	

H.4 Fertilizer use

Table H.28: Calculated nitrogen use for wheat

Country	$Prod^a$ DM Mton/yr	$N_{rate}{}^{bg}$ kg N/ha	$f_{fA}{}^c$ %	$N_{use}{}^d$ kg N/ha	$Y_{biological}{}^e$ DM ton/ha	a^f kg N/DM ton
Argentina	28,2	40	88^g	35,2	4,6	7,7
Austria	2,6	115	$95{,}1^h$	109	9,6	11,4
Belgium	3	155	100^h	155	15,1	10,3
Brazil	4,6	12	100^h	12	3,3	3,6
Canada	46,3	50	100^h	50	4,3	11,6
Chile	3	100	100^g	100	7,6	13,2
Czech Republic	7,6	104	85^h	88,4	8,4	10,5
Egypt	11,8	169	100^g	169	11,6	14,6
Ethiopia	2,3	13	$77{,}4^h$	10,1	2,4	4,2
France	67,8	80	$6{,}3^h$	5	13,3	0,4
Germany	39,3	165	100^h	165	14	11,7
Guatemala	0	120	80^g	96	3,8	25,1
Hungary	8,2	103	68^h	70,1	7,5	9,3
India	133	99,6	21^g	20,9	5	4,2
Iran, Islamic Rep of	18,2	56	100^h	56	3,3	17,1
Italy	13,9	82	$98{,}3^h$	80,6	5,9	13,6
Japan	1,2	117	$93{,}4^h$	109	6,8	16,1
Lithuania	2	24	100^h	24	5,6	4,3
Mexico	6,3	130	80^g	104	8,8	11,8
Netherlands	1,9	190	100^h	190	15,1	12,6
New Zealand	0,6	100	100^h	100	11,9	8,4
Poland	16,8	65	100^h	65	6,5	10,1
Slovakia	3	76,3	85^h	64,9	7,6	8,5
South Africa	4,2	30	100^g	30	4,5	6,7
Spain	10,4	95	100^h	95	4,8	20
Sweden	4	120	100^h	120	11,1	10,8
Switzerland	1,1	155	$95{,}9^h$	149	11,2	13,3
Turkey	36,9	64,6	88^g	57	3,9	14,5
United Kingdom	27,8	183	100^h	183	14,4	12,7
United States of America	118	70	90^g	63	5,3	11,9
Weighted average	-	-	-	-	-	9,1

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Table H.29: Calculated nitrogen use for maize

Country	$Prod^a$ DM Mton/yr	$N_{rate}{}^{bg}$ kg N/ha	$f_{fA}{}^c$ %	$N_{use}{}^d$ kg N/ha	$Y_{biological}{}^e$ DM ton/ha	a^f kg N/DM ton
Argentina	30,4	28	85^g	23,8	10,2	2,3
Austria	3,3	120	$95{,}2^h$	114	18,1	6,3
Belgium	0,8	65	$91{,}6^h$	59,6	21,2	2,8
Brazil	63,6	40	100^h	40	5,4	7,4
Canada	15,4	156	98^h	153	13,5	11,3
Chile	1,5	200	100^g	200	17	11,8
China	222	130	100^g	130	9	14,4
Czech Republic	0,6	83	$24{,}7^h$	20,5	12,3	1,7
Egypt	11,7	233	100^g	233	13,8	16,9
Ethiopia	5,3	6,8	$65{,}7^h$	4,5	3,2	1,4
France	30,2	170	$99{,}8^h$	170	16,7	10,2
Germany	6,1	150	$95{,}2^h$	143	16,5	8,7
Guatemala	1,9	100,0	100^g	100	3,2	30,9
Hungary	12,5	115	$10{,}6^h$	12,2	11,1	1,1
India	22,2	41,7	$2{,}5^g$	1	3,4	0,3
Italy	18,8	184	100^h	184	18	10,2
Japan	0	200	100^h	200	4,6	43,1
Malaysia	0,1	91,6	$29{,}1^h$	26,6	4,3	6,3
Mexico	34,6	80	75^g	60	4,6	13
Netherlands	0,3	44	100^h	44	16,2	2,7
New Zealand	0,3	120	100^h	120	19,2	6,3
Nigeria	9,3	5,9	100^h	5,9	2,6	2,3
Pakistan	3,1	-	-	$5{,}2^i$	3,2	1,6
Philippines	8,2	58	80^g	46,4	3,2	14,3
Poland	1,4	-	-	$35{,}7^i$	11	3,2
Slovakia	1,3	85,8	79^h	67,9	9,8	7
South Africa	17	55	95^g	52,2	4,6	11,3
Spain	8,1	225	94^h	211	17,8	11,9
Switzerland	0,4	160	100^h	160	17,8	9
Tanzania	5,1	80	10^g	8	1,7	4,8
Thailand	8,2	56	80^g	44,8	6,6	6,8
Turkey	4,2	129	97^g	125	7,8	16,1
United States of America	459	150	100^g	150	15,9	9,4
Viet Nam	3,5	105	90^h	94,5	5	18,9
Weighted average	-	-	-	-	-	11,4

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Table H.30: Calculated nitrogen use for sorghum

Country	$Prod^{a}$ $DM\ Mton/yr$	$N_{rate}{}^{b}$ $kg\ N/ha$	$f_{fA}{}^{c}$ %	$N_{use}{}^{d}$ $kg\ N/ha$	$Y_{biological}{}^{e}$ $DM\ ton/ha$	a^{f} $kg\ N/DM\ ton$
China	10,7	90	100^{g}	90	11,3	8
Colombia	0,7	100	90^{g}	90	10,3	8,8
Guatemala	0,2	100,0	90^{g}	90	3,9	23,1
India	25,9	29,2	3^{g}	0,9	2,6	0,3
Mexico	19,8	80	60^{g}	48	10,3	4,7
Tanzania, United Rep of	2	20	10^{g}	2	3,1	0,6
United States of America	45,3	100,0	90^{g}	90	13,4	6,7
Weighted average	-	-	-	-	-	4,8

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Table H.31: Calculated nitrogen use for sugarbeet

Country	$Prod^a$ $DM\ Mton/yr$	$N_{rate}{}^b$ $kg\ N/ha$	$f_{fA}{}^c$ %	$N_{use}{}^d$ $kg\ N/ha$	$Y_{biological}{}^e$ $DM\ ton/ha$	a^f $kg\ N/DM\ ton$
Austria	0,9	85	100^h	85	20	4,3
Belgium	1,9	110	100^h	110	20,1	5,5
Chile	1	200	95^g	190	20,2	9,4
China	3,6	120	100^g	120	8,4	14,3
Czech Republic	1	90	$69{,}9^h$	62,9	14	4,5
Egypt	0,7	23	100^g	23	14,8	1,6
France	10	145	$43{,}2^h$	62,6	22,6	2,8
Germany	8,4	145	$95{,}4^h$	138	17,7	7,8
Hungary	0,9	63	$74{,}4^h$	46,9	12,9	3,6
Italy	4,1	90	$97{,}8^h$	88	14,7	6
Japan	1,2	176	100^h	176	17,7	10
Latvia	0,1	176	$94{,}2^g$	166	10,7	15,5
Lithuania	0,3	57	100^h	57	9,8	5,8
Netherlands	2,1	108	100^h	108	18,2	5,9
Poland	4,3	121	100^h	121	11,8	10,3
Slovakia	0,4	57	$80{,}2^h$	45,7	11,8	3,9
Spain	2,6	178	$96{,}4^h$	172	19,2	9
Sweden	0,8	100,0	95^h	95	14,3	6,6
Switzerland	0,4	143	100^h	143	21,4	6,7
United Kingdom	3,1	100,0	$94{,}2^h$	94,2	17	5,5
United States of America	8,9	120	100^g	120	15,6	7,7
Weighted average	-	-	-	-	-	6,9

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Table H.32: Calculated nitrogen use for sugarcane

Country	$Prod^a$ DM Mton/yr	${N_{rate}}^b$ kg N/ha	${f_{fA}}^c$ %	${N_{use}}^d$ kg N/ha	${Y_{biological}}^e$ DM ton/ha	a^f kg N/DM ton
Argentina	8,3	80	65^g	52	28,7	1,8
Australia	16,8	229	100^h	229	40,9	5,6
Brazil	152	55	100^h	55	30,9	1,8
China	35,6	150	100^g	150	30,8	4,9
Colombia	15,2	100	70^g	70	38,5	1,8
Cuba	15,7	63	$56,3^g$	35,5	14,7	2,4
Egypt	6,7	80	100^g	80	52,5	1,5
Guatemala	7,8	100,0	70^g	70	44,4	1,6
Indonesia	11,5	90	80^g	72	30	2,4
India	129	125	$5,4^g$	6,7	31,1	0,2
Japan	0,7	226	$98,6^h$	223	30	7,4
Mexico	20,9	100,0	90^g	90	33,4	2,7
Philippines	11,7	85	80^g	68	32,8	2,1
Thailand	23,1	70	95^g	66,5	25,1	2,6
United States of America	14,1	$100,0^g$	100	100	35,4	2,8
Viet Nam	6,6	105	85^g	89,2	22,2	4
South Africa	10	92	95^g	87,4	28,7	3
Weighted average	-	-	-	-	-	1,9

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Table H.33: Calculated nitrogen use for soy

Country	$Prod^a$ DM Mton/yr	$N_{rate}{}^b$ kg N/ha	$f_{fA}{}^c$ %	$N_{use}{}^d$ kg N/ha	$Y_{biological}{}^e$ DM ton/ha	a^f kg N/DM ton
Argentina	44,5	2	100^h	2	5,4	0,4
Brazil	73,8	8	100^h	8	5,6	1,4
Canada	5,8	25	100^h	25	5,6	4,4
China	34,5	60	98^g	58,8	4	14,8
Colombia	0,1	20	65^g	13	4,9	2,7
Guatemala	0,1	20	60^g	12	6,9	1,7
Hungary	0,1	52	$79{,}7^h$	41,5	4,7	8,9
Japan	0,5	30	$96{,}2^h$	28,9	4,1	7,1
Mexico	0,3	30	95^g	28,5	3,6	7,9
Nigeria	0,9	2,6	$88{,}4^h$	2,3	1,8	1,3
Philippines	0	20	20^g	4	2,8	1,4
Thailand	0,7	12	60^g	7,2	3,3	2,2
Turkey	0,1	30,4	$98{,}1^g$	29,8	6,2	4,8
United States of America	172	30	70^g	21	5,9	3,5
Viet Nam	0,3	45	80^g	36	2,7	13,5
South Africa	0,4	7	100^h	7	3,7	1,9
Weighted average	-	-	-	-	-	3,8

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Table H.34: Calculated nitrogen use for rape

Country	$Prod^a$ DM Mton/yr	$N_{rate}{}^b$ kg N/ha	$f_{fA}{}^c$ %	$N_{use}{}^d$ kg N/ha	$Y_{biological}{}^e$ DM ton/ha	a^f kg N/DM ton
Canada	16,2	75	$99{,}9^h$	74,9	3,3	22,8
Chile	0,1	140	100^g	140	6	23,4
China	23,4	125	100^g	125	3,4	36,9
Czech Republic	1,8	147	100^h	147	6,1	24,2
India	12,5	69,1	$3{,}4^g$	2,3	2,1	1,1
Japan	0	118	100^h	118	3,7	32,2
New Zealand	0	60	$45{,}2^h$	27,1	4,4	6,2
United States of America	1,6	150	95^g	142	3,5	40,6
Weighted average	-	-	-	-	-	24,4

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Table H.35: Calculated nitrogen use for oil palm

Country	$Prod^a$	${N_{rate}}^b$	${f_{fA}}^c$	${N_{use}}^d$	${Y_{biological}}^e$	a^f
	DM Mton/yr	*kg N/ha*	%	*kg N/ha*	*DM ton/ha*	*kg N/DM ton*
Colombia	0,6	100	100^g	100	23,9	4,2
Guatemala	0,1	80	100^g	80	24,9	3,2
Indonesia	8,5	95	80^g	76	23,2	3,3
Malaysia	13,5	-	-	$98{,}6^i$	24,6	4
Philippines	0,1	75	80^g	60	17,6	3,4
Thailand	0,7	105	98^g	103	21,3	4,8
Weighted average	-	-	-	-	-	3,8

a) Average production of the primary crop in the period 1997-2001, source: [FAO, 2007a]
b) Application rate of fertilizer on fertilized area [FAO, 2007b]
c) Fertilized area
d) Average nitrogen use
e) Total biological yield
f) Ratio between average nitrogen use and total biological yield: $N_{use}/Y_{biological}$
g) Source: [FAO, 2007b]
h) Calculated with the fertilized area and the cultivated area.
i) Calculated with the national consumption and the cultivated area.

Appendix I

Water - results appendix

I.1 Green and blue crop water use of crop category 1-3

Table I.1: Current green and blue crop water use of wheat of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	155	155	0	1,8	1550	0
Australia	227	217	10	3,2	2170	3
Austria	366	219	147	6,7	2190	98
Belgium	547	427	120	1,9	4270	23
Brazil	174	174	0	7,6	1740	0
Burkina Faso	-	-	-	-	-	-
Canada	500	239	261	1	2390	27
Chile	179	178	1	28,3	1780	4
China[g]	311	194	118	22,8	1940	268
-idem-[h]	278	109	169	-	-	-
-idem-[h]	328	156	172	-	-	-
-idem-[h]	328	315	13	-	-	-
Colombia	272	272	0	11,6	2720	0
Cuba	-	-	-	-	-	-
Czech Republic	491	368	123	1,4	3680	17
Egypt	630	56	574	89,6	563	5140
Ethiopia	377	312	65	1,5	3120	10
France	573	357	216	11,8	3570	255
Germany	540	469	72	3,8	4690	27
Guatemala	377	377	0	3,8	3770	0
Hungary	539	343	196	5,2	3430	101
India[g]	340	161	179	42,3	1610	758
-idem-[h]	230	56	174	-	-	-
-idem-[h]	450	265	185	-	-	-
Indonesia	-	-	-	-	-	-
Iran	218	207	11	31,7	2070	36
Italy[g]	315	266	49	28,9	2660	142
-idem-[h]	229	220	9	-	-	-
-idem-[h]	231	225	6	-	-	-
-idem-[h]	485	353	132	-	-	-
Japan	370	367	3	28,7	3670	8
Kazakhstan	523	214	309	1,4	2140	43
Korea, Republic of	550	528	23	28,1	5280	64

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.2: Current green and blue crop water use of wheat of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	427	281	146	0,1	2810	1
Lithuania	431	308	123	0,1	3080	2
Malaysia	-	-	-	-	-	-
Mali	458	446	12	0	4460	0
Mexico	327	63	264	45	625	1190
Netherlands	422	384	38	28,5	3840	108
New Zealand	308	286	22	17,8	2860	39
Nigeria	397	390	7	1,2	3900	1
Pakistan[g]	339	109	230	55,7	1090	1280
-idem-[h]	163	87	76	-	-	-
-idem-[h]	213	170	43	-	-	-
-idem-[h]	640	70	570	-	-	-
Philippines	-	-	-	-	-	-
Poland	430	332	98	0,6	3320	6
Russian Federation	525	281	244	1,6	2810	40
Slovakia	532	307	225	9,9	3070	224
South Africa	397	261	135	5,9	2610	80
Spain	242	167	74	13,9	1670	103
Sudan	523	355	167	6,6	3550	111
Sweden	412	285	128	9	2850	115
Switzerland	431	411	21	6,2	4110	13
Tanzania	505	294	211	1,3	2940	28
Thailand	391	376	15	13,2	3760	20
Turkey	627	311	316	11,6	3110	368
Ukraine	558	229	328	5,4	2290	179
United Kingdom	481	333	148	1,8	3330	27
United States[g]	590	373	217	10,5	3730	229
-idem-[h]	812	592	220	-	-	-
-idem-[h]	671	306	365	-	-	-
-idem-[h]	287	221	66	-	-	-
Viet Nam	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.3: Current green and blue crop water use of maize of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	501	304	197	2,1	3040	40
Australia	152	152	0	5,2	1520	0
Austria	324	204	120	5,7	2040	69
Belgium	380	263	117	1,6	2630	19
Brazil	370	368	3	3,5	3680	1
Burkina Faso	486	390	96	0,7	3900	6
Canada	413	310	103	0,8	3100	8
Chile	125	125	0	26,7	1250	0
China[g]	399	289	110	18,4	2890	203
-idem-[h]	563	383	180	-	-	-
-idem-[h]	293	148	145	-	-	-
-idem-[h]	341	334	6	-	-	-
Colombia	281	281	0	11	2810	0
Cuba	495	416	79	17,7	4160	140
Czech Republic	383	262	120	2,3	2620	27
Egypt	468	56	412	90,4	560	3720
Ethiopia	366	321	45	1,5	3210	7
France	451	239	212	12	2390	254
Germany	421	247	174	3,8	2470	65
Guatemala	374	374	0	3,8	3740	0
Hungary	478	256	222	5,4	2560	119
India	426	407	19	31,4	4070	60
Indonesia	423	423	0	9,9	4230	0
Iran	173	131	42	29,1	1310	121
Italy	456	345	112	28,6	3450	320
Japan	318	316	1	28,7	3160	4
Kazakhstan	740	104	636	10,7	xx	xx
Korea, Republic of	456	446	10	31,9	4460	31

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.4: Current green and blue crop water use of maize of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-
Malaysia	412	406	5	5,2	4060	3
Mali	499	336	163	4,6	3360	75
Mexico[g]	413	323	90	7,9	3230	71
-idem-[h]	319	70	249	-	-	-
-idem-[h]	474	453	20	-	-	-
-idem-[h]	447	446	1	-	-	-
Netherlands	346	245	100	28,5	2450	286
New Zealand	270	260	9	17,9	2600	16
Nigeria	561	216	345	2,3	xx	xx
Pakistan	405	178	227	55,2	1780	1250
Philippines	399	399	0	11,2	3990	0
Poland	276	216	59	0,5	2160	3
Russian Federation	473	291	182	2	2910	36
Slovakia	453	269	183	11,5	2690	210
South Africa	626	260	366	5,8	2600	212
Spain	542	153	389	13,5	xx	xx
Sudan	540	343	198	4,2	3430	83
Sweden	-	-	-	-	-	-
Switzerland	366	346	20	6,4	3460	13
Tanzania	416	401	15	1,1	4010	2
Thailand[g]	396	393	3	19,8	3930	6
-idem-[h]	383	380	2	-	-	-
-idem-[h]	455	454	1	-	-	-
Turkey	481	167	314	9,7	1670	304
Ukraine	488	214	274	5,7	2140	158
United Kingdom	-	-	-	-	-	-
United States	606	398	208	5,9	3980	123
Viet Nam	431	431	0	18,8	4310	0

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.5: Current green and blue crop water use of sorghum of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	532	360	173	2,6	3600	45
Australia	605	449	156	5,2	4490	80
Austria	-	-	-	-	-	-
Belgium	-	-	-	-	-	-
Brazil	387	387	0	3,3	3870	0
Burkina Faso	497	394	102	0,6	3940	6
Canada	-	-	-	-	-	-
Chile	-	-	-	-	-	-
China	305	217	88	16,7	2170	148
Colombia	270	270	0	11,3	2700	0
Cuba	495	428	67	5,5	4280	37
Czech Republic	-	-	-	-	-	-
Egypt	336	55	282	90,8	546	2560
Ethiopia	372	321	51	1,5	3210	8
France	302	186	116	11,8	1860	137
Germany	-	-	-	-	-	-
Guatemala	376	376	0	4,1	3760	0
Hungary	410	235	176	5,4	2350	95
India[g]	418	368	50	23,2	3680	116
-idem-[h]	393	385	8	-	-	-
-idem-[h]	439	333	106	-	-	-
-idem-[h]	421	386	35	-	-	-
Indonesia	-	-	-	-	-	-
Iran	-	-	-	-	-	-
Italy	353	255	98	29	2550	284
Japan	-	-	-	-	-	-
Kazakhstan	506	154	352	4,8	xx	xx
Korea, Republic of	400	376	25	38,7	3760	96

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.6: Current green and blue crop water use of sorghum of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-
Malaysia	-	-	-	-	-	-
Mali	494	236	258	4,5	2360	117
Mexico	495	210	285	15,1	2100	431
Netherlands	-	-	-	-	-	-
New Zealand	-	-	-	-	-	-
Nigeria	544	239	306	2,3	2390	70
Pakistan	415	188	227	56,5	1880	1280
Philippines	-	-	-	-	-	-
Poland	-	-	-	-	-	-
Russian Federation	-	-	-	-	-	-
Slovakia	400	243	157	16,1	2430	253
South Africa	442	177	264	4,1	1770	108
Spain	115	115	0	12,8	1150	0
Sudan	491	327	163	7,2	3270	117
Sweden	-	-	-	-	-	-
Switzerland	-	-	-	-	-	-
Tanzania	503	295	208	1	2950	21
Thailand	399	398	0,5	20,1	3980	1
Turkey		0		25,6	0	0
Ukraine	459	174	284	10,6	1740	301
United Kingdom	-	-	-	-	-	-
United States	638	332	306	12,4	3320	378
Viet Nam	335	306	28	0	3060	0

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.7: Current green and blue crop water use of sugarbeet of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	-	-	-	-	-	-
Australia	-	-	-	-	-	-
Austria	344	230	114	5,9	2300	68
Belgium	470	321	149	2,2	3210	33
Brazil	-	-	-	-	-	-
Burkina Faso	-	-	-	-	-	-
Canada	430	367	63	1,4	3670	9
Chile	193	184	9	28,6	1840	26
China	582	413	169	15,3	4130	258
Colombia	-	-	-	-	-	-
Cuba	-	-	-	-	-	-
Czech Republic	416	303	113	1,4	3030	16
Egypt	659	56	603	92,5	563	5580
Ethiopia	701	629	72	0	6290	0
France	420	292	128	11,1	2920	142
Germany	429	318	110	4	3180	44
Guatemala	-	-	-	-	-	-
Hungary	533	305	228	5,1	3050	117
India	-	-	-	-	-	-
Indonesia	-	-	-	-	-	-
Iran	234	214	20	31,7	2140	62
Italy[g]	206	194	12	28,8	1940	350
-idem-[h]	127	127	0	-	-	-
-idem-[h]	259	226	33	-	-	-
-idem-[h]	232	228	4	-	-	-
Japan	360	360	0	28,7	3600	0
Kazakhstan	760	147	613	9,9	xx	xx
Korea, Republic of	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.8: Current green and blue crop water use of sugarbeet of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	418	299	119	0,1	2990	1
Lithuania	420	317	103	0,1	3170	2
Malaysia	-	-	-	-	-	-
Mali	-	-	-	-	-	-
Mexico	538	358	181	94,3	3580	1700
Netherlands	399	300	98	28	3000	275
New Zealand	-	-	-	-	-	-
Nigeria	-	-	-	-	-	-
Pakistan	804	366	438	0	3660	0
Philippines	-	-	-	-	-	-
Poland	436	317	120	0,6	3170	7
Russian Federation	203	172	31	2,6	1720	8
Slovakia	521	315	206	9,7	3150	200
South Africa	-	-	-	-	-	-
Spain	516	282	234	14	2820	328
Sudan	-	-	-	-	-	-
Sweden	425	252	173	8,8	2520	153
Switzerland	423	404	19	5,7	4040	11
Tanzania	-	-	-	-	-	-
Thailand	-	-	-	-	-	-
Turkey	608	162	447	11,4	xx	xx
Ukraine	494	342	152	5,4	3420	82
United Kingdom	383	245	138	1,7	2450	24
United States	641	433	208	16,1	4330	334
Viet Nam	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.9: Current green and blue crop water use of sugarcane of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	1260	463	799	2,7	xx	xx
Australia	1570	628	938	4,1	6280	386
Austria	-	-	-	-	-	-
Belgium	-	-	-	-	-	-
Brazil	1340	968	374	6,4	9680	238
Burkina Faso	1970	459	1510	0,1	xx	xx
Canada	-	-	-	-	-	-
Chile	-	-	-	-	-	-
China	1220	951	271	12,8	9510	348
Colombia	844	840	4	11,3	8400	5
Cuba	1570	1050	514	17,7	10530	909
Czech Republic	-	-	-	-	-	-
Egypt	1650	92,1	1560	90,7	921	14160
Ethiopia	1320	761	557	1,2	7610	70
France	-	-	-	-	-	-
Germany	-	-	-	-	-	-
Guatemala	1300	847	455	3,7	8470	171
Hungary	-	-	-	-	-	-
India[g]	1620	589	1030	40,1	5890	4150
-idem-[h]	1434	543	890	-	-	-
-idem-[h]	1813	634	1179	-	-	-
Indonesia	1550	1310	234	9,9	13130	233
Iran	1510	229	1280	31,9	2290	4100
Italy	-	-	-	-	-	-
Japan	544	544	0	28,8	5440	0
Kazakhstan	-	-	-	-	-	-
Korea, Republic of	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.10: Current green and blue crop water use of sugarcane of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-
Malaysia	1380	1310	68	6,3	13120	43
Mali	2130	500	1630	11,6	xx	xx
Mexico[g]	1350	823	528	6,4	8230	338
-idem-[h]	1341	641	700	-	-	-
-idem-[h]	1362	1005	356	-	-	-
Netherlands	-	-	-	-	-	-
New Zealand	-	-	-	-	-	-
Nigeria	1880	662	1220	0,9	xx	xx
Pakistan	1400	601	802	56,2	6010	4500
Philippines	1390	1130	258	11,2	11290	289
Poland	-	-	-	-	-	-
Russian Federation	-	-	-	-	-	-
Slovakia	-	-	-	-	-	-
South Africa	1310	808	503	5,5	8080	277
Spain	1260	349	913	0	xx	xx
Sudan	2190	359	1830	7,5	xx	xx
Sweden	-	-	-	-	-	-
Switzerland	-	-	-	-	-	-
Tanzania	1770	711	1060	1,3	7110	134
Thailand[g]	1470	878	592	20,1	8780	1190
-idem-[h]	1405	711	694	-	-	-
-idem-[h]	1531	823	708	-	-	-
-idem-[h]	1472	1099	373	-	-	-
Turkey	-	-	-	-	-	-
Ukraine	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-
United States	1630	980	647	12,6	9800	817
Viet Nam	1140	908	237	19,4	9080	460

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.11: Current green and blue crop water use of soy of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	590	380	210	4,2	3800	88
Australia	172	172	0	2,2	1720	0
Austria	439	237	203	1,3	2370	26
Belgium	-	-	-	-	-	-
Brazil	299	299	0	5,5	2990	0
Burkina Faso	343	313	30	0	3130	0
Canada	432	309	123	1,5	3090	19
Chile	-	-	-	-	-	-
China	521	363	158	1,4	3630	23
Colombia	301	300	0	3	3000	0
Cuba	-	-	-	-	-	-
Czech Republic	400	262	138	1,7	2620	24
Egypt	398	55	343	1,1	xx	xx
Ethiopia	424	332	93	1,7	3320	15
France	399	222	177	1,4	2220	25
Germany	435	246	189	2,5	2460	48
Guatemala	413	413	0	2	4130	0
Hungary	479	261	218	1,4	2610	31
India	464	407	57	1,2	4070	7
Indonesia	434	434	0	1,8	4340	0
Iran	177	133	43	2,3	1330	10
Italy	482	295	187	1,5	2950	28
Japan	330	327	3	2,4	3270	0,7
Kazakhstan	551	169	381	1,9	xx	xx
Korea, Republic of	471	448	23	3,1	4480	7

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.12: Current green and blue crop water use of soy of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	383	247	136	2,2	2470	30
Lithuania	-	-	-	-	-	-
Malaysia	285	265	20	1,7	2650	3
Mali	322	320	2	0	3200	0
Mexico	517	259	259	1,5	2590	40
Netherlands	-	-	-	-	-	-
New Zealand	-	-	-	-	-	-
Nigeria	359	253	106	3,8	2530	40
Pakistan	310	310	0	1,1	3100	0
Philippines	290	290	0	0	2900	0
Poland	292	217	75	1,7	2170	13
Russian Federation	507	237	270	1,5	2370	41
Slovakia	467	270	197	1,1	2700	22
South Africa	253	211	42	2,9	2110	12
Spain	129	129	0	1,2	1290	0
Sudan	-	-	-	-	-	-
Sweden	-	-	-	-	-	-
Switzerland	377	357	21	2,6	3570	5
Tanzania, United Republic of	349	230	119	1,9	2300	23
Thailand	288	279	9	1,3	2790	1
Turkey	496	217	279	1,7	2170	46
Ukraine	541	199	342	1,3	xx	xx
United Kingdom	-	-	-	-	-	-
United States	571	387	184	1,3	3870	25
Viet Nam	479	478	0	1,4	4780	0

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.13: Current green and blue crop water use of rape of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	504	288	216	2,7	2880	59
Australia	337	272	65	5,7	2720	37
Austria	456	269	187	6,4	2690	119
Belgium	469	318	151	1,5	3180	23
Brazil	483	483	0	0,6	4830	0
Burkina Faso	-	-	-	-	-	-
Canada	485	240	245	1,4	2400	33
Chile	130	130	0	29,1	1300	0
China[g]	354	332	22	20,6	3320	45
-idem-[h]	290	255	35	-	-	-
-idem-[h]	417	409	8	-	-	-
Colombia	-	-	-	-	-	-
Cuba	-	-	-	-	-	-
Czech Republic	423	299	123	1,4	2990	17
Egypt	-	-	-	-	-	-
Ethiopia	446	422	24	1,6	4220	4
France	491	342	148	12	3420	178
Germany	428	289	139	3,9	2890	54
Guatemala	-	-	-	-	-	-
Hungary	537	303	234	4,7	3030	111
India[g]	502	266	236	35,2	2660	831
-idem-[h]	467	265	202	-	-	-
-idem-[h]	537	267	270	-	-	-
Indonesia	-	-	-	-	-	-
Iran	-	-	-	-	-	-
Italy	542	350	192	25,5	3500	489
Japan	363	362	1	0	3620	0
Kazakhstan	569	191	378	4,3	xx	xx
Korea, Republic of	545	538	7	36,6	5380	27

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
g) This country uses more than one crop location, this value corresponds with the (unweighted) average of those locations.
h) This country uses more than one crop location, this value corresponds with either the first, second, or third crop location of the country.
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.14: Current green and blue crop water use of rape of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	351	285	66	0,1	2850	1
Lithuania	425	313	112	0,1	3130	1
Malaysia	-	-	-	-	-	-
Mali	-	-	-	-	-	-
Mexico	409	409	0	0	4090	0
Netherlands	401	295	106	31,2	2950	331
New Zealand	290	273	17	16,3	2730	28
Nigeria	-	-	-	-	-	-
Pakistan	444	194	250	58,4	1940	1460
Philippines	-	-	-	-	-	-
Poland	453	280	173	0,6	2800	11
Russian Federation	553	278	274	1,7	2780	47
Slovakia	525	313	212	9,6	3130	204
South Africa	-	-	-	-	-	-
Spain	159	154	5	13,5	1540	7
Sudan	-	-	-	-	-	-
Sweden	427	272	155	9	2720	139
Switzerland	426	406	20	5,4	4060	11
Tanzania	-	-	-	-	-	-
Thailand	-	-	-	-	-	-
Turkey	716	170	546	0	xx	xx
Ukraine	411	301	110	4,3	3010	47
United Kingdom	414	247	167	1,8	2470	30
United States	440	232	208	1,7	2320	35
Viet Nam	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.15: Current green and blue crop water use of oil palm of 25 countries: A-K

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	-	-	-	-	-	-
Australia	-	-	-	-	-	-
Austria	-	-	-	-	-	-
Belgium	-	-	-	-	-	-
Brazil	1290	971	324	0,5	9710	15
Burkina Faso	-	-	-	-	-	-
Canada	-	-	-	-	-	-
Chile	-	-	-	-	-	-
China	990	419	571	0	4190	0
Colombia	890	823	67	11,4	8230	77
Cuba	-	-	-	-	-	-
Czech Republic	-	-	-	-	-	-
Egypt	-	-	-	-	-	-
Ethiopia	-	-	-	-	-	-
France	-	-	-	-	-	-
Germany	-	-	-	-	-	-
Guatemala	1170	855	319	4,3	8550	137
Hungary	-	-	-	-	-	-
India	-	-	-	-	-	-
Indonesia	1380	1210	167	8,6	12140	144
Iran	-	-	-	-	-	-
Italy	-	-	-	-	-	-
Japan	-	-	-	-	-	-
Kazakhstan	-	-	-	-	-	-
Korea, Republic of	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

Table I.16: Current green and blue crop water use of oil palm of 25 countries: L-Z

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Latvia	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-
Malaysia	1220	1220	0	2,8	12180	0
Mali	-	-	-	-	-	-
Mexico	1030	599	429	3,1	5990	133
Netherlands	-	-	-	-	-	-
New Zealand	-	-	-	-	-	-
Nigeria	2050	339	1710	2,3	xx	xx
Pakistan	-	-	-	-	-	-
Philippines	1260	1080	176	11,2	10800	196
Poland	-	-	-	-	-	-
Russian Federation	-	-	-	-	-	-
Slovakia	-	-	-	-	-	-
South Africa	-	-	-	-	-	-
Spain	-	-	-	-	-	-
Sudan	-	-	-	-	-	-
Sweden	-	-	-	-	-	-
Switzerland	-	-	-	-	-	-
Tanzania	1450	978	476	0,3	9780	12
Thailand	1300	782	513	19,5	7820	1000
Turkey	-	-	-	-	-	-
Ukraine	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-
United States	-	-	-	-	-	-
Viet Nam	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use
xx) Values are excluded as the blue and green crop water use together are lower than 40% of the CWR.

I.2 Green and blue crop water use of crop category 4

Table I.17: Current green and blue crop water use of eucalyptus

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	1100	-	-	-	11010	-
Australia	1080	-	-	-	10800	-
Belgium	-	-	-	-	-	-
Brazil	1320	-	-	-	13240	-
Chile	1100	-	-	-	10960	-
China	919	-	-	-	9190	-
France	-	-	-	-		-
India	1320	-	-	-	13180	-
Indonesia	1570	-	-	-	15670	-
Iran	1090	-	-	-	10890	-
Italy	828	-	-	-	8280	-
Lithuania	-	-	-	-	-	-
Netherlands	-	-	-	-	-	-
New Zealand	-	-	-	-	-	-
Philippines	-	-	-	-	-	-
Poland	-	-	-	-	-	-
Slovakia	-	-	-	-	-	-
South Africa	1320	-	-	-	13220	-
Sudan	1570	-	-	-	15750	-
Ukraine	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-
United States	-	-	-	-	-	-
Viet Nam	1160	-	-	-	11620	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use
f) Blue crop water use

Table I.18: Current green and blue crop water use of pine

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	1330	-	-	-	13300	-
Australia	1270	-	-	-	12690	-
Belgium	707	-	-	-	7070	-
Brazil	1600	-	-	-	16050	-
Chile	1250	-	-	-	12500	-
China	1100	-	-	-	10970	-
France	744	-	-	-	7440	-
India	1520	-	-	-	15210	-
Indonesia	1890	-	-	-	18860	-
Iran	-	-	-	-	-	-
Italy	998	-	-	-	9980	-
Lithuania	632	-	-	-	6320	-
Netherlands	625	-	-	-	6250	-
New Zealand	938	-	-	-	9380	-
Philippines	1730	-	-	-	17330	-
Poland	666	-	-	-	6660	-
Slovakia	811	-	-	-	8110	-
South Africa	1560	-	-	-	15570	-
Sudan	-	-	-	-	-	-
Ukraine	-	-	-	-	-	-
United Kingdom	652	-	-	-	6520	-
United States	1200	-	-	-	12020	-
Viet Nam	1400	-	-	-	13960	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use.
f) Blue crop water use.

Table I.19: Current green and blue crop water use of poplar

Country	$\sum CWR^a$ $mm/period$	$\sum P_{effective}{}^b$ $mm/period$	$\sum IR^c$ $mm/period$	$f_{Ai}{}^d$ %	$CWU_{green}{}^e$ m^3/ha	$CWU_{blue}{}^f$ m^3/ha
Argentina	1110	-	-	-	11080	-
Australia	-	-	-	-	-	-
Belgium	574	-	-	-	5740	-
Brazil	1340	-	-	-	13370	-
Chile	1100	-	-	-	10980	-
China	923	-	-	-	9230	-
France	-	-	-	-	-	-
India	1320	-	-	-	13190	-
Indonesia	-	-	-	-	-	-
Iran	1090	-	-	-	10900	-
Italy	832	-	-	-	8320	-
Lithuania	-	-	-	-		-
Netherlands	511	-	-	-	5110	-
New Zealand	-	-	-	-	-	-
Philippines	-	-	-	-	-	-
Poland	553	-	-	-	5530	-
Slovakia	679	-	-	-	6790	-
South Africa	-	-	-	-	-	-
Sudan	-	-	-	-	-	-
Ukraine	605	-	-	-	6050	-
United Kingdom	-	-	-	-	-	-
United States	-	-	-	-	-	-
Viet Nam	-	-	-	-	-	-

a) Crop water requirement expressed per cultivation period.
b) Effective precipitation expressed per cultivation period.
c) Irrigation requirement expressed per cultivation period.
d) fraction of cultivated crop area which is equipped for irrigation.
e) Green crop water use.
f) Blue crop water use.

Appendix J

Water footprint of bioenergy - results appendix

J.1 Current system - primary energy

Table J.1: Virtual water content of primary energy from wheat in the current system for 25 countries: A-K

Country	Prod[a] *DM Mton/yr*	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Argentina	28,2	17,4	0	4	21,4
Australia	42,5	30,6	0	4,7	35,3
Austria	2,6	11,7	0,5	5,9	18,1
Belgium	3	14,6	0,1	5,3	20
Brazil	4,6	27,2	0	1,9	29,1
Burkina Faso	-	-	-	-	-
Canada	46,3	28,6	0,3	6	35
Chile	3	12,1	0	6,8	18,9
China	204	13,7	1,9	4,7	20,3
Colombia	0,1	35,9	0	4,7	40,5
Cuba	-	-	-	-	-
Czech Republic	7,6	22,5	0,1	5,4	28
Egypt	11,8	2,5	22,9	7,5	32,9
Ethiopia	2,3	67,8	0,2	2,2	70,2
France	67,8	13,8	1	0,2	15
Germany	39,3	17,2	0,1	6	23,3
Guatemala	0	50,7	0	12,9	63,6
Hungary	8,2	23,5	0,7	4,8	29
India	133	16,6	7,8	2,2	26,5
Indonesia	-	-	-	-	-
Iran	18,2	32,6	,6	8,8	42
Italy	13,9	23,1	1,2	7	31,3
Japan	1,2	27,9	0,1	8,3	36,3
Kazakhstan	17,7	61,5	1,2	4,7	67,5
Korea, Republic of	0	42,7	0,5	4,7	47,9
Weighted average A-Z	-	21,5	2,9	4,7	29,0

a) Average production of the primary crop in the period 1997-2001. [dry total biological yield]
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.2: Virtual water content of primary energy from wheat in the current system for 25 countries: L-Z

Country	Prod[a] *DM Mton/yr*	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	0,8	29,5	0	4,7	34,2
Lithuania	2	28,2	0	2,2	30,4
Malaysia	-	-	-	-	-
Mali	0	56,3	0	4,7	61
Mexico	6,3	3,7	7	6,1	16,7
Netherlands	1,9	13,1	0,4	6,5	19,9
New Zealand	0,6	12,4	0,2	4,3	16,8
Nigeria	0,1	58,8	0	4,7	63,5
Pakistan	35,2	13,2	15,5	4,7	33,3
Philippines	-	-	-	-	-
Poland	16,8	26,4	0	5,2	31,7
Russian Federation	69,4	45,4	0,6	4,7	50,7
Slovakia	3	20,8	1,5	4,4	26,7
South Africa	4,2	30	,9	3,4	34,3
Spain	10,4	18,1	1,1	10,3	29,5
Sudan	0,7	47	1,5	4,7	53,2
Sweden	4	13,2	0,5	5,5	19,2
Switzerland	1,1	18,9	0,1	6,8	25,8
Tanzania, United Republic of	0,2	59,5	0,6	4,7	64,8
Thailand	0	157	0,8	4,7	163
Turkey	36,9	40,6	4,8	7,5	52,9
Ukraine	29,6	24,3	1,9	4,7	30,9
United Kingdom	27,8	11,9	0,1	6,6	18,6
United States	118	36,4	2,2	6,2	44,8
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	23,5	2,9	4,7	31

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.3: Virtual water content of primary energy from maize in the current system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Argentina	30,4	15,1	0,2	1,2	16,4
Australia	0,7	8	0	5,7	13,7
Austria	3,3	5,7	0,2	3,2	9
Belgium	0,8	6,2	0	1,4	7,7
Brazil	63,6	34,2	0	3,7	37,9
Burkina Faso	0,8	64,2	0,1	5,7	70
Canada	15,4	11,5	0	5,7	17,2
Chile	1,5	3,7	0	5,9	9,6
China	222	16,1	1,1	7,2	24,4
Colombia	1,9	40,1	0	7,1	47,2
Cuba	0,4	60,9	2	5,7	68,7
Czech Republic	0,6	10,7	0,1	0,8	11,6
Egypt	11,7	2	13,6	8,5	24,1
Ethiopia	5,3	50,6	0,1	0,7	51,5
France	30,2	7,2	0,8	5,1	13,1
Germany	6,1	7,5	0,2	4,4	12,1
Guatemala	1,9	58,3	0	15,6	73,8
Hungary	12,5	11,6	0,5	0,6	12,7
India	22,2	59,4	0,9	0,2	60,4
Indonesia	17,8	41,6	0	5,7	47,3
Iran	2	5,5	,5	5,7	11,8
Italy	18,8	9,6	,9	5,1	15,6
Japan	0	34,3	0	21,7	56
Kazakhstan	0,4	-	-	-	-
Korea, Republic of	0,1	29,5	,2	5,7	35,5
Weighted average A-Z	-	18,4	0,8	5,1	24,5

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.4: Virtual water content of primary energy from maize in the current system for 25 countries: L-Z

Country	Prod[a] *DM Mton/yr*	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	0,1	48,1	0	3,1	51,2
Mali	0,7	61,5	1,4	5,7	68,6
Mexico	34,6	35,1	0,8	6,5	42,4
Netherlands	0,3	7,6	0,9	1,4	9,9
New Zealand	0,3	6,8	0	3,1	10
Nigeria	9,3	-	-	-	-
Pakistan	3,1	27,7	19,4	0,8	47,9
Philippines	8,2	62	0	7,2	69,2
Poland	1,4	9,9	0	1,6	11,5
Russian Federation	2,6	36,1	0,4	5,7	42,3
Slovakia	1,3	13,9	1,1	3,5	18,5
South Africa	17	28,3	2,3	5,7	36,4
Spain	8,1	4,3	1,5	6	11,8
Sudan	0,1	136	3,3	5,7	145
Sweden	-	-	-	-	-
Switzerland	0,4	9,8	0	4,5	14,3
Tanzania, United Republic of	5,1	120	0	2,4	122
Thailand	8,2	29,9	0	3,4	33,4
Turkey	4,2	10,8	2	8,1	20,8
Ukraine	6,4	19,6	1,4	5,7	26,8
United Kingdom	-	-	-	-	-
United States	459	12,6	0,4	4,7	17,7
Viet Nam	3,5	43,4	0	9,5	52,9
Weighted average A-Z	-	18,4	0,8	5,1	24,5

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.5: Virtual water content of primary energy from sorghum in the current system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^b$ $m^3/GJ\ HHV$	${v_{blue}}^c$ $m^3/GJ\ HHV$	${v_{grey}}^d$ $m^3/GJ\ HHV$	${v_{total}}^e$ $m^3/GJ\ HHV$
Argentina	10,3	12,5	0,2	2,4	15
Australia	5,5	24,9	0,4	2,4	27,8
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil	2,2	34,4	0	2,4	36,8
Burkina Faso	3,7	72,9	0,1	2,4	75,4
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China	10,7	9,7	0,7	4	14,4
Colombia	0,7	13,2	0	4,4	17,6
Cuba	0	87,9	0,8	2,4	91,1
Czech Republic	-	-	-	-	-
Egypt	2,9	1,5	7,1	2,4	11
Ethiopia	4,7	40,7	0,1	2,4	43,2
France	1,2	4,7	0,3	2,4	7,5
Germany	-	-	-	-	-
Guatemala	0,2	48,6	0	11,6	60,3
Hungary	0	17,6	0,7	2,4	20,8
India	25,9	72,2	2,3	0,2	74,7
Indonesia	-	-	-	-	-
Iran	-	-	-	-	-
Italy	0,6	6,5	0,7	2,4	9,6
Japan	-	-	-	-	-
Kazakhstan	-	-	-	-	-
Korea, Republic of	0	41,1	1	2,4	44,6
Weighted average A-Z	-	31,5	1,6	2,4	35,6

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.6: Virtual water content of primary energy from sorghum in the current system for 25 countries: L-Z

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^b$ $m^3/GJ\ HHV$	${v_{blue}}^c$ $m^3/GJ\ HHV$	${v_{grey}}^d$ $m^3/GJ\ HHV$	${v_{total}}^e$ $m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	-	-	-	-	-
Mali	1,9	40,9	2	2,4	45,3
Mexico	19,8	10,3	2,1	2,3	14,7
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	24,2	33	1	2,4	36,4
Pakistan	0,7	47,8	32,5	2,4	82,7
Philippines	0	-	-	-	-
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	0	16,6	1,7	2,4	20,8
South Africa	1,1	10,3	0,6	2,4	13,3
Spain	0,1	3,9	0	2,4	6,3
Sudan	10,7	84,4	3	2,4	89,9
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania, United Republic of	2	47,2	0,3	0,3	47,9
Thailand	0,5	38	0	2,4	40,4
Turkey	-	-	-	-	-
Ukraine	0	31,2	5,4	2,4	39
United Kingdom	-	-	-	-	-
United States	45,3	12,5	1,4	3,4	17,3
Viet Nam	0	-	-	-	-
Weighted average A-Z	-	31,5	1,6	2,4	35,6

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.7: Virtual water content of primary energy from sugarbeet in the current system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^b$ $m^3/GJ\ HHV$	${v_{blue}}^c$ $m^3/GJ\ HHV$	${v_{grey}}^d$ $m^3/GJ\ HHV$	${v_{total}}^e$ $m^3/GJ\ HHV$
Argentina	-	-	-	-	-
Australia	-	-	-	-	-
Austria	0,9	6,6	0,2	2,4	9,3
Belgium	1,9	9,2	0,1	3,1	12,4
Brazil	-	-	-	-	-
Burkina Faso	-	-	-	-	-
Canada	0,2	14,3	0	4	18,3
Chile	1	5,3	0,1	5,4	10,8
China	3,6	28,3	1,8	8,2	38,2
Colombia	-	-	-	-	-
Cuba	-	-	-	-	-
Czech Republic	1	12,4	0,1	2,6	15,1
Egypt	0,7	2,2	21,6	0,9	24,7
Ethiopia	-	-	-	-	-
France	10	7,4	0,4	1,6	9,4
Germany	8,4	10,4	0,1	4,5	15
Guatemala	-	-	-	-	-
Hungary	0,9	13,6	0,5	2,1	16,2
India	-	-	-	-	-
Indonesia	-	-	-	-	-
Iran	1,5	14,3	0,4	4	18,7
Italy	4,1	7,6	0,1	3,4	11,2
Japan	1,2	11,7	0	5,7	17,4
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-
Weighted average A-Z	-	13,9	0,7	4,0	18,6

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.8: Virtual water content of primary energy from sugarbeet in the current system for 25 countries: L-Z

Country	Prod[a] *DM Mton/yr*	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	0,1	16,1	0	8,9	25
Lithuania	0,3	18,7	0	3,4	22
Malaysia	-	-	-	-	-
Mali	-	-	-	-	-
Mexico	0	16,2	7,7	4	28
Netherlands	2,1	9,5	0,9	3,4	13,8
New Zealand	-	-	-	-	-
Nigeria	-	-	-	-	-
Pakistan	0	24,5	0	4	28,5
Philippines	-	-	-	-	-
Poland	4,3	15,5	0	5,9	21,5
Russian Federation	-	17,1	0,1	4	21,1
Slovakia	0,4	15,4	1	2,2	18,6
South Africa	-	-	-	-	-
Spain	2,6	8,5	1	5,2	14,6
Sudan	-	-	-	-	-
Sweden	0,8	10,1	0,6	3,8	14,6
Switzerland	0,4	10,9	0	3,8	14,7
Tanzania, United Republic of	-	-	-	-	-
Thailand	-	-	-	-	-
Turkey	-	-	-	-	-
Ukraine	4,8	35,8	0,9	4	40,6
United Kingdom	3,1	8,3	0,1	3,2	11,6
United States	8,9	15,9	1,2	4,4	21,6
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	13,9	0,7	4,0	18,6

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.9: Virtual water content of primary energy from sugarcane in the current system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^{b}$ $m^3/GJ\ HHV$	${v_{blue}}^{c}$ $m^3/GJ\ HHV$	${v_{grey}}^{d}$ $m^3/GJ\ HHV$	${v_{total}}^{e}$ $m^3/GJ\ HHV$
Argentina	-	-	-	-	-
Australia	-	7,8	0,5	2,9	11,2
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil	152	15,9	0,4	0,9	17,2
Burkina Faso	-	-	-	-	-
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China	35,6	15,7	0,6	2,5	18,8
Colombia	15,2	11,1	0	0,9	12
Cuba	15,7	36,5	3,1	1,2	40,9
Czech Republic	-	-	-	-	-
Egypt	6,7	0,9	13,7	0,8	15,4
Ethiopia	-	8,8	0,1	1	9,9
France	-	-	-	-	-
Germany	-	-	-	-	-
Guatemala	7,8	9,7	0,2	0,8	10,7
Hungary	-	-	-	-	-
India	129	9,7	6,8	0,1	16,6
Indonesia	11,5	22,3	0,4	1,2	24
Iran	1,1	3,1	5,5	1	9,6
Italy	-	-	-	-	-
Japan	0,7	9,3	0	3,8	13
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-
Weighted average A-Z	-	14,0	2,9	1,0	18,1

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.10: Virtual water content of primary energy from sugarcane in the current system for 25 countries: L-Z

Country	Prod[a] $DM\ Mton/yr$	$v_{green}{}^{b}$ $m^3/GJ\ HHV$	$v_{blue}{}^{c}$ $m^3/GJ\ HHV$	$v_{grey}{}^{d}$ $m^3/GJ\ HHV$	$v_{total}{}^{e}$ $m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	0,7	20	0,1	1	21,1
Mali	-	-	-	-	-
Mexico	20,9	12,6	0,5	1,4	14,5
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	-	-	-	-	-
Pakistan	21,6	14,6	11	1	26,5
Philippines	11,7	17,6	0,4	1,1	19,1
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa	10	14,3	0,5	1,6	16,4
Spain	-	-	-	-	-
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania, United Republic of	0,6	8,9	,2	1	10,1
Thailand	23,1	17,8	2,4	1,3	21,6
Turkey	-	-	-	-	-
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	14,1	14,1	1,2	1,4	16,7
Viet Nam	6,6	20,8	1,1	2	23,9
Weighted average A-Z	-	14,0	2,9	1,0	18,1

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.11: Virtual water content of primary energy from soy in the current system for 25 countries: A-K

Country	Prod[a] *DM Mton/yr*	${v_{green}}^{b}$ $m^3/GJ\ HHV$	${v_{blue}}^{c}$ $m^3/GJ\ HHV$	${v_{grey}}^{d}$ $m^3/GJ\ HHV$	${v_{total}}^{e}$ $m^3/GJ\ HHV$
Argentina	-	33,3	0,8	0,2	34,3
Australia	-	19,2	0	1,8	21,1
Austria	0,1	21	0,2	1,8	23,1
Belgium	-	-	-	-	-
Brazil	73,8	25,3	0	0,7	26
Burkina Faso	-	59	0	1,8	60,8
Canada	5,8	26,1	0,2	2,1	28,3
Chile	-	-	-	-	-
China	34,5	43,5	0,3	7	50,8
Colombia	0,1	29,1	0	1,3	30,4
Cuba	-	-	-	-	-
Czech Republic	0	38,8	0,4	1,8	41
Egypt	-	-	-	-	-
Ethiopia	-	19,8	0,1	1,8	21,7
France	0,6	17,5	0,2	1,8	19,5
Germany	0	25,8	0,5	1,8	28,2
Guatemala	0,1	28,5	0	,8	29,3
Hungary	0,1	26,7	0,3	4,2	31,2
India	14,7	82,8	0,1	1,8	84,8
Indonesia	2,7	74	0	1,8	75,8
Iran	0,3	16,8	0,1	1,8	18,7
Italy	2,3	16,7	0,2	1,8	18,7
Japan	0,5	38,1	0	3,4	41,5
Kazakhstan	-	-	-	-	-
Korea, Republic of	0,3	64,7	0,1	1,8	66,7
Weighted average A-Z	-	33,8	0,2	1,8	35,8

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.12: Virtual water content of primary energy from soy in the current system for 25 countries: L-Z

Country	Prod[a] *DM Mton/yr*	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	0	43,9	0,5	1,8	46,2
Lithuania	-	-	-	-	-
Malaysia	0	164	0,2	1,8	166
Mali	-	-	-	-	-
Mexico	0,3	34	0,5	3,7	38,3
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	-	67,4	1,1	0,6	69,1
Pakistan	0	53	0	1,8	54,8
Philippines	0	49,4	0	0,7	50,1
Poland	0	193	1,2	1,8	196
Russian Federation	-	54,9	0,9	1,8	57,7
Slovakia	0	37,2	0,3	1,8	39,3
South Africa	0,4	27,1	0,2	0,9	28,1
Spain	-	11,7	0	1,8	13,5
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland	0	24,2	0	1,8	26,1
Tanzania, United Republic of	0	131	1,3	1,8	134
Thailand	0,7	39,7	0	1	40,8
Turkey	-	16,7	0,4	2,3	19,4
Ukraine	0,1	-	-	-	-
United Kingdom	-	-	-	-	-
United States	172	31	0,2	1,7	32,8
Viet Nam	0,3	85,5	0	6,4	91,9
Weighted average A-Z	-	33,8	0,2	1,8	35,8

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.13: Virtual water content of primary energy from rape in the current system for 25 countries: A-K

Country	Prod[a]	v_{green}[b]	v_{blue}[c]	v_{grey}[d]	v_{total}[e]
	$DM\ Mton/yr$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$
Argentina	0	43	0,9	11,6	55,4
Australia	3,9	43,7	0,6	11,6	55,8
Austria	0,3	21,1	0,9	11,6	33,6
Belgium	0	19,8	0,1	11,6	31,5
Brazil	0,1	65,1	0	11,6	76,6
Burkina Faso	-	-	-	-	-
Canada	16,2	34,5	0,5	10,8	45,7
Chile	0,1	10,3	0	11,1	21,4
China	23,4	46,3	0,6	17,4	64,4
Colombia	-	-	-	-	-
Cuba	-	-	-	-	-
Czech Republic	1,8	23,3	0,1	11,4	34,9
Egypt	-	-	-	-	-
Ethiopia	0	115	0,1	11,6	127
France	8,3	22,4	1,2	11,6	35,1
Germany	8,5	17,3	0,3	11,6	29,2
Guatemala	-	-	-	-	-
Hungary	0,4	37,5	1,4	11,6	50,4
India	12,5	61,2	19,1	0,5	80,8
Indonesia	-	-	-	-	-
Iran	-	-	-	-	-
Italy	0,1	70,5	9,8	11,6	91,9
Japan	0	46,8	0	15,2	62
Kazakhstan	0	-	-	-	-
Korea, Republic of	0	77,3	0,4	11,6	89,2
Weighted average A-Z	-	38,2	3,6	11,6	53,3

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.14: Virtual water content of primary energy from rape in the current system for 25 countries: L-Z

Country	Prod[a] $DM\ Mton/yr$	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	0	42,6	0	11,6	54,1
Lithuania	0,2	41,8	0	11,6	53,4
Malaysia	-	-	-	-	-
Mali	-	-	-	-	-
Mexico	0	69,3	0	11,6	80,9
Netherlands	0	17,8	2	11,6	31,4
New Zealand	0	29,4	0,3	2,9	32,6
Nigeria	-	-	-	-	-
Pakistan	0,7	41,6	31,2	11,6	84,3
Philippines	-	-	-	-	-
Poland	2,2	26,3	0,1	11,6	37,9
Russian Federation	0,3	64,8	1,1	11,6	77,5
Slovakia	0,4	32,1	2,1	11,6	45,7
South Africa	-	-	-	-	-
Spain	0,1	19,4	0,1	11,6	31
Sudan	-	-	-	-	-
Sweden	0,3	24,8	1,3	11,6	37,7
Switzerland	0,1	27,5	0,1	11,6	39,1
Tanzania, United Republic of	-	-	-	-	-
Thailand	-	-	-	-	-
Turkey	-	-	-	-	-
Ukraine	0,2	63	1	11,6	75,6
United Kingdom	3,3	17,1	0,2	11,6	28,8
United States	1,6	31,3	0,5	19,2	51
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	38,2	3,6	11,6	53,3

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.15: Virtual water content of primary energy from oil palm in the current system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	$v_{green}{}^{b}$ $m^3/GJ\ HHV$	$v_{blue}{}^{c}$ $m^3/GJ\ HHV$	$v_{grey}{}^{d}$ $m^3/GJ\ HHV$	$v_{total}{}^{e}$ $m^3/GJ\ HHV$
Argentina	-	-	-	-	-
Australia	-	-	-	-	-
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil	0,1	33,7	0,1	1,7	35,5
Burkina Faso	-	-	-	-	-
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China	0,3	10,1	0	1,7	11,8
Colombia	0,6	16	0,1	1,9	18
Cuba	-	-	-	-	-
Czech Republic	-	-	-	-	-
Egypt	-	-	-	-	-
Ethiopia	-	-	-	-	-
France	-	-	-	-	-
Germany	-	-	-	-	-
Guatemala	0,1	15,9	0,3	1,5	17,7
Hungary	-	-	-	-	-
India	-	-	-	-	-
Indonesia	8,5	24,2	0,3	1,5	26
Iran	-	-	-	-	-
Italy	-	-	-	-	-
Japan	-	-	-	-	-
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-
Weighted average A-Z	-	22,9	0,2	1,7	24,8

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.16: Virtual water content of primary energy from oil palm in the current system for 25 countries: L-Z

Country	Prod[a] *DM Mton/yr*	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	13,5	22,9	0	1,9	24,7
Mali	-	-	-	-	-
Mexico	0	14,4	0,3	1,7	16,4
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	-	-	-	-	-
Pakistan	-	-	-	-	-
Philippines	0,1	28,4	0,5	1,6	30,5
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa	-	-	-	-	-
Spain	-	-	-	-	-
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania, United Republic of	0	25,1	0	1,7	26,9
Thailand	0,7	17	2,2	2,2	21,5
Turkey	-	-	-	-	-
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	-	-	-	-	-
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	22,9	0,2	1,7	24,8

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.17: Virtual water content of primary energy from eucalyptus in the current system

Country	Prod[a] $DM\ Mton/yr$	$v_{green}{}^{a}$ $m^3/GJ\ HHV$	$v_{blue}{}^{b}$ $m^3/GJ\ HHV$	$v_{grey}{}^{c}$ $m^3/GJ\ HHV$	$v_{total}{}^{d}$ $m^3/GJ\ HHV$
Argentina	-	26,2	-	3,8	30
Australia	-	44,2	-	3,8	48
Belgium	-	-	-	-	-
Brazil	-	22,4	-	3,8	26,2
Chile	-	32,7	-	3,8	36,5
China	-	136	-	3,8	140
France	-	-	-	-	-
India	-	100	-	3,8	104
Indonesia	-	62,8	-	3,8	66,6
Iran	-	118	-	3,8	122
Italy	-	39,4	-	3,8	43,2
Lithuania	-	-	-	-	-
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Philippines	-	-	-	-	-
Poland	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa	-	43,8	-	3,8	47,6
Sudan	-	92,2	-	3,8	96
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	-	-	-	-	-
Viet Nam	-	104	0	3,8	108
Median	-	53,5	-	3,8	57,3

a) Average production of the primary crop in the period 1997-2001, no data is available for trees.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.18: Virtual water content of primary energy from pine in the current system

Country	Prod[a] *DM Mton/yr*	$v_{green}{}^{a}$ m^3/GJ HHV	$v_{blue}{}^{b}$ $m^3/GJ\ HHV$	$v_{grey}{}^{c}$ $m^3/GJ\ HHV$	$v_{total}{}^{d}$ $m^3/GJ\ HHV$
Argentina	-	41,3	-	3,8	45,1
Australia	-	75,6	-	3,8	79,5
Belgium	-	43,1	-	3,8	46,9
Brazil	-	37,6	-	3,8	41,4
Chile	-	39,6	-	3,8	43,5
China	-	125	-	3,8	128
France	-	61,2	-	3,8	65
India	-	290	-	3,8	293
Indonesia	-	180	-	3,8	183
Iran	-	-	-	-	-
Italy	-	36,2	-	3,8	40
Lithuania	-	75,2	-	3,8	79
Netherlands	-	63,5	-	3,8	67,3
New Zealand	-	38,6	-	3,8	42,4
Philippines	-	106	-	3,8	109
Poland	-	66,7	-	3,8	70,5
Slovakia	-	138	-	3,8	142
South Africa	-	88,9	-	3,8	92,7
Sudan	-	-	-	-	-
Ukraine	-	-	-	-	-
United Kingdom	-	55,1	-	3,8	58,9
United States	-	158	-	3,8	162
Viet Nam	-	266	-	3,8	270
Median	-	70,9	-	3,8	74,7

a) Average production of the primary crop in the period 1997-2001, no data is available for trees.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.19: Virtual water content of primary energy from poplar in the current system

Country	Prod[a] *DM Mton/yr*	v_{green}[a] $m^3/GJ\ HHV$	v_{blue}[b] $m^3/GJ\ HHV$	v_{grey}[c] $m^3/GJ\ HHV$	v_{total}[d] $m^3/GJ\ HHV$
Argentina	-	33,8	-	3,8	37,6
Australia	-	-	-	-	-
Belgium	-	29,1	-	3,8	32,9
Brazil	-	50,9	-	3,8	54,7
Chile	-	23,9	-	3,8	27,7
China	-	63,3	-	3,8	67,1
France	-	-	-	-	-
India	-	44,6	-	3,8	48,4
Indonesia	-	-	-	-	-
Iran	-	97,7	-	3,8	101
Italy	-	34,2	-	3,8	38
Lithuania	-	-	-	-	-
Netherlands	-	27,8	-	3,8	31,6
New Zealand	-	-	-	-	-
Philippines	-	-	-	-	-
Poland	-	36,8	-	3,8	40,6
Slovakia	-	70,1	-	3,8	73,9
South Africa	-	-	-	-	-
Sudan	-	-	-	-	-
Ukraine	-	52,6	-	3,8	56,4
United Kingdom	-	-	-	-	-
United States	-	-	-	-	-
Viet Nam	-	-	-	-	-
Median	-	40,7	-	3,8	44,5

a) Average production of the primary crop in the period 1997-2001, no data is available for trees.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

J.2 Current system - secondary energy - first transformation

Table J.20: Virtual water content of liquid biofuels produced with first transformation of crops produced in the current system for 25 countries: A-K ($m^3/GJ\ HHV$)

Country	ethanol					biodiesel		
	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Argentina	88	66	92	-	-	77	140	-
Australia	150	55	170	-	49	47	140	-
Austria	75	36	-	21	-	52	83	-
Belgium	83	31	-	28	-	-	78	-
Brazil	120	150	230	-	75	58	190	100
Burkina Faso	-	280	460	-	-	140	-	-
Canada	150	70	-	41	-	64	110	-
Chile	78	39	-	24	-	-	53	-
China	84	99	88	86	82	110	160	35
Colombia	170	190	110	-	52	68	-	53
Cuba	-	280	560	-	180	-	-	-
Czech Republic	120	47	-	34	-	92	86	-
Egypt	140	97	67	56	67	-	-	-
Ethiopia	290	210	270	-	43	49	310	-
France	62	53	46	21	-	44	87	-
Germany	97	49	-	34	-	63	72	-
Guatemala	260	300	370	-	47	66	-	52
Hungary	120	51	130	36	-	70	130	-
India	110	240	460	-	72	190	200	-
Indonesia	-	190	-	-	100	170	-	76
Iran	170	48	-	42	42	42	-	-
Italy	130	63	59	25	-	42	230	-
Japan	150	230	-	39	57	93	150	-
Kazakhstan	280	-	-	-	-	-	-	-
Korea, Republic of	200	140	270	-	-	150	220	-
Based on average crops	130	99	220	42	79	81	130	73

Table J.21: Virtual water content of liquid biofuels produced with first transformation of crops produced in the current system for 25 countries: L-Z ($m^3/GJ\ HHV$)

Country	ethanol					biodiesel		
	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Latvia	140	-	-	56	-	100	130	-
Lithuania	130	-	-	50	-	-	130	-
Malaysia	-	210	-	-	92	370	-	72
Mali	250	280	280	-	-	-	-	-
Mexico	69	170	90	63	63	86	200	48
Netherlands	82	40	-	31	-	-	78	-
New Zealand	70	40	-	-	-	-	81	-
Nigeria	260	-	220	-	-	160	-	-
Pakistan	140	190	510	64	120	120	210	-
Philippines	-	280	-	-	83	110	-	89
Poland	130	47	-	48	-	440	94	-
Russian Federation	210	170	-	48	-	130	190	-
Slovakia	110	74	130	42	-	88	110	-
South Africa	140	150	82	-	71	63,3	-	-
Spain	120	48	39	33	-	30	77	-
Sudan	220	580	550	-	-	-	-	-
Sweden	80	-	-	33	-	-	93	-
Switzerland	110	58	-	33	-	59	97	-
Tanzania	270	490	290	-	44	300	-	79
Thailand	670	140	250	-	94	92	-	63
Turkey	220	84	-	-	-	44	-	-
Ukraine	130	110	240	91	-	-	190	-
United Kingdom	77	-	-	26	-	-	71	-
United States	190	72	110	49	72	74	130	-
Viet Nam	-	210	-	-	100	210	-	-
Based on average crops	130	99	220	42	79	81	130	73

Table J.22: Virtual water content of power and charcoal produced with first transformation of crops produced in the current system for 25 countries: A-K ($m^3/GJ\ HHV$)

Country	power						charcoal		
	soy	rape	oil palm	eucalyptus	pine	poplar	eucalyptus	pine	poplar
Argentina	300	540	-	150	220	180	77	120	96
Australia	190	540	-	230	390	-	120	200	-
Austria	200	320	-	-	-	-	-	-	-
Belgium	-	310	-	-	230	160	-	120	84
Brazil	230	740	410	130	200	270	67	110	140
Burkina Faso	540	-	-	-	-	-	-	-	-
Canada	250	440	-	-	-	-	-	-	-
Chile	-	210	-	180	210	140	94	110	71
China	450	620	140	680	630	33	360	330	170
Colombia	270	-	210	-	-	-	-	-	-
Cuba	-	-	-	-	-	-	-	-	-
Czech Republic	360	340	-	-	-	-	-	-	-
Egypt	-	-	-	-	-	-	-	-	-
Ethiopia	190	1200	-	-	-	-	-	-	-
France	170	340	-	-	320	-	-	170	-
Germany	250	280	-	-	-	-	-	-	-
Guatemala	260	-	200	-	-	-	-	-	-
Hungary	280	490	-	-	-	-	-	-	-
India	750	780	-	510	1400	240	270	750	120
Indonesia	670	-	300	320	890	-	170	470	-
Iran	170	-	-	600	-	490	310	-	260
Italy	160	890	-	210	200	190	110	100	97
Japan	360	600	-	-	-	-	-	-	-
Kazakhstan	-	-	-	-	-	-	-	-	-
Korea, Republic of	590	860	-	-	-	-	-	-	-
Based on average crops	320	520	270	-	-	-	-	-	-
Based on median crops	-	-	-	280	360	220	150	190	110

Table J.23: Virtual water content of power and charcoal produced with first transformation of crops produced in the current system for 25 countries: L-Z ($m^3/GJ\ HHV$)

Country	power						charcoal		
	soy	rape	oil palm	eucalyptus	pine	poplar	eucalyptus	pine	poplar
Latvia	410	520	-	-	-	-	-	-	-
Lithuania	-	52	-	-	380	-	-	200	-
Malaysia	1500	-	280	-	-	-	-	-	-
Mali	-	-	-	-	-	-	-	-	-
Mexico	340	780	188	-	-	-	-	-	-
Netherlands	-	300	-	-	330	150	-	170	81
New Zealand	-	320	-	-	210	-	-	110	-
Nigeria	610	-	-	-	-	-	-	-	-
Pakistan	480	810	-	-	-	-	-	-	-
Philippines	440	-	350	-	530	-	-	280	-
Poland	1720	370	-	-	340	200	-	180	110
Russian Federation	510	750	-	-	-	-	-	-	-
Slovakia	350	440	-	-	690	360	-	3640	190
South Africa	250	-	-	230	450	-	120	240	-
Spain	120	300	-	-	-	-	-	-	-
Sudan	-	-	-	470	-	-	250	-	-
Sweden	-	360	-	-	-	-	-	-	-
Switzerland	230	380	-	-	-	-	-	-	-
Tanzania, United Republic of	1200	-	310	-	-	-	-	-	-
Thailand	360	-	250	-	-	-	-	-	-
Turkey	170	-	-	-	-	-	-	-	-
Ukraine	-	730	-	-	-	270	-	-	140
United Kingdom	-	280	-	-	290	-	-	150	-
United States	290	490	-	-	790	-	-	420	-
Viet Nam	810	-	-	530	1300	-	280	690	-
Based on average crops	320	520	270	-	-	-	-	-	-
Based on median crops	-	-	-	280	360	220	150	190	110

J.3 HEI system - primary energy

Table J.24: Virtual water content of primary energy from wheat in the HEI-system for 25 countries: A-K

Country	Prod[a]	v_{green}[b]	v_{blue}[c]	v_{grey}[d]	v_{total}[e]
	DM Mton/yr	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$
Argentina	28,2	5,5	0	5,3	10,8
Australia	42,5	8,3	0,4	5,3	14
Austria	2,6	5	3,3	5,3	13,6
Belgium	3	11,4	3,2	5,3	19,9
Brazil	4,6	10,1	0	5,3	15,5
Burkina Faso	-	-	-	-	-
Canada	46,3	9,3	10,1	5,3	24,7
Chile	3	5,3	0	5,3	10,6
China	204	5,9	3,6	5,3	14,9
Colombia	0,1	9,4	0	5,3	14,7
Cuba	-	-	-	-	-
Czech Republic	7,6	8,5	2,8	5,3	16,6
Egypt	11,8	2,1	21	5,3	28,4
Ethiopia	2,3	14,7	3,1	5,3	23,1
France	67,8	9,4	5,7	5,3	20,4
Germany	39,3	10,4	1,6	5,3	17,3
Guatemala	0	20,4	0	5,3	25,7
Hungary	8,2	8,5	4,9	5,3	18,7
India	133	8,6	9,5	5,3	23,4
Indonesia	-	-	-	-	-
Iran	18,2	6,2	0,3	5,3	11,8
Italy	13,9	6,9	1,3	5,3	13,5
Japan	1,2	10,1	0,1	5,3	15,5
Kazakhstan	17,7	6,7	9,7	5,3	21,7
Korea, Republic of	0	12,4	0,5	5,3	18,3
Weighted average A-Z	-	7,8	5,7	5,3	18,9

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.25: Virtual water content of primary energy from wheat in the HEI-system for 25 countries: L-Z

Country	Prod[a]	${v_{green}}^b$	${v_{blue}}^c$	${v_{grey}}^d$	${v_{total}}^e$
	DM Mton/yr	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$
Latvia	0,8	7,7	4	5,3	17,1
Lithuania	2	7,8	3,1	5,3	16,2
Malaysia	-	-	-	-	-
Mali	0	26,7	0,7	5,3	32,8
Mexico	6,3	2,7	11,4	5,3	19,4
Netherlands	1,9	8,6	0,9	5,3	14,8
New Zealand	0,6	9,3	0,7	5,3	15,3
Nigeria	0,1	21,4	0,4	5,3	27,1
Pakistan	35,2	4,5	9,5	5,3	19,3
Philippines	-	-	-	-	-
Poland	16,8	7,4	2,2	5,3	14,9
Russian Federation	69,4	9,7	8,5	5,3	23,5
Slovakia	3	7,1	5,2	5,3	17,7
South Africa	4,2	9,9	5,1	5,3	20,3
Spain	10,4	5	2,2	5,3	12,6
Sudan	0,7	22,9	10,8	5,3	39
Sweden	4	7,9	3,6	5,3	16,8
Switzerland	1,1	9,4	0,5	5,3	15,2
Tanzania, United Republic of	0,2	16	11,5	5,3	32,8
Thailand	0	27,9	1,1	5,3	34,3
Turkey	36,9	6,8	6,9	5,3	18,9
Ukraine	29,6	5,5	7,9	5,3	18,7
United Kingdom	27,8	8,9	3,9	5,3	18,1
United States	118	10,1	5,9	5,3	21,3
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	7,8	5,7	5,3	18,9

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.26: Virtual water content of primary energy from maize in the HEI-system for 25 countries: A-K

Country	Prod[a] DM Mton/yr	$v_{green}{}^{b}$ $m^3/GJ\ HHV$	$v_{blue}{}^{c}$ $m^3/GJ\ HHV$	$v_{grey}{}^{d}$ $m^3/GJ\ HHV$	$v_{total}{}^{e}$ $m^3/GJ\ HHV$
Argentina	30,4	5,6	3,6	1,4	10,6
Australia	0,7	3	0	1,4	4,4
Austria	3,3	5	3	1,4	9,4
Belgium	0,8	17,5	7,8	1,4	26,7
Brazil	63,6	9,1	0,1	1,4	10,6
Burkina Faso	0,8	8,8	2,2	1,4	12,4
Canada	15,4	8,3	2,8	1,4	12,5
Chile	1,5	2,9	0	1,4	4,3
China	222	6,1	2,3	1,4	9,9
Colombia	1,9	6,9	0	1,4	8,3
Cuba	0,4	10,6	2	1,4	14,1
Czech Republic	0,6	6,7	3,1	1,4	11,2
Egypt	11,7	1	7,3	1,4	9,7
Ethiopia	5,3	7,1	1	1,4	9,5
France	30,2	5,4	4,8	1,4	11,6
Germany	6,1	6	4,2	1,4	11,6
Guatemala	1,9	13,5	0	1,4	14,9
Hungary	12,5	6	5,2	1,4	12,6
India	22,2	8,6	0,4	1,4	10,4
Indonesia	17,8	10,7	0	1,4	12,1
Iran	2	2,4	0,8	1,4	4,6
Italy	18,8	6,6	2,1	1,4	10,1
Japan	0	8	0	1,4	9,4
Kazakhstan	-	-	-	-	-
Korea, Republic of	0,1	9	0,2	1,4	10,6
Weighted average A-Z	-	7,3	3,2	1,4	12,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.27: Virtual water content of primary energy from maize in the HEI-system for 25 countries: L-Z

Country	Prod[a] $DM\ Mton/yr$	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	0,1	-	-	-	-
Mali	0,7	7,6	3,7	1,4	12,7
Mexico	34,6	6,7	1,9	1,4	10
Netherlands	0,3	15,7	6,4	1,4	23,6
New Zealand	0,3	6,5	0,2	1,4	8,2
Nigeria	-	-	-	-	-
Pakistan	3,1	3,4	4,3	1,4	9
Philippines	8,2	11,5	0	1,4	12,9
Poland	1,4	13,5	3,7	1,4	18,6
Russian Federation	2,6	7,6	4,8	1,4	13,8
Slovakia	1,3	6,8	4,7	1,4	12,9
South Africa	17	5	7	1,4	13,4
Spain	8,1	3	7,5	1,4	11,9
Sudan	0,1	7,5	4,3	1,4	13,2
Sweden	-	-	-	-	-
Switzerland	0,4	9,2	0,5	1,4	11,1
Tanzania, United Republic of	5,1	9,2	0,3	1,4	10,9
Thailand	8,2	11	0,1	1,4	12,5
Turkey	4,2	3	5,7	1,4	10,2
Ukraine	6,4	5,2	6,6	1,4	13,2
United Kingdom	-	-	-	-	-
United States	459	8	4,2	1,4	13,6
Viet Nam	3,5	10	0	1,4	11,4
Weighted average A-Z	-	7,3	3,2	1,4	12,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.28: Virtual water content of primary energy from sorghum in the HEI-system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^b$ $m^3/GJ\ HHV$	${v_{blue}}^c$ $m^3/GJ\ HHV$	${v_{grey}}^d$ $m^3/GJ\ HHV$	${v_{total}}^e$ $m^3/GJ\ HHV$
Argentina	10,3	5,2	2,5	3,4	11,1
Australia	5,5	6,8	2,3	3,4	12,5
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil	2,2	6,9	0	3,4	10,3
Burkina Faso	3,7	6,9	1,8	3,4	12
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China	10,7	3,8	1,5	3,4	8,7
Colombia	0,7	4,8	0	3,4	8,1
Cuba	0	12,2	1,9	3,4	17,4
Czech Republic	-	-	-	-	-
Egypt	2,9	0,8	4,2	3,4	8,4
Ethiopia	4,7	5,5	0,9	3,4	9,7
France	-	-	-	-	-
Germany	-	-	-	-	-
Guatemala	0,2	13,3	0	3,4	16,6
Hungary	0	5,2	3,9	3,4	12,5
India	25,9	6	0,8	3,4	10,1
Indonesia	-	-	-	-	-
Iran	-	-	-	-	-
Italy	0,6	4,5	1,7	3,4	9,6
Japan	-	-	-	-	-
Kazakhstan	-	-	-	-	-
Korea, Republic of	0	13,2	0,9	3,4	17,4
Weighted average A-Z	-	4,9	3,3	3,4	11,6

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.29: Virtual water content of primary energy from sorghum in the HEI-system for 25 countries: L-Z

Country	Prod[a] $DM\ Mton/yr$	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	-	-	-	-	-
Mali	1,9	4,1	4,4	3,4	11,9
Mexico	19,8	3,4	4,6	3,4	11,4
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	24,2	4,1	5,3	3,4	12,8
Pakistan	0,7	2,7	3,2	3,4	9,3
Philippines	-	-	-	-	-
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa	1,1	2,7	4,1	3,4	10,2
Spain	0,1	1,9	0	3,4	5,3
Sudan	10,7	5,4	2,7	3,4	11,5
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania, United Republic of	2	5,2	3,7	3,4	12,2
Thailand	0,5	8,9	0	3,4	12,3
Turkey	-	-	-	-	-
Ukraine	0	3,1	5,1	3,4	11,5
United Kingdom	-	-	-	-	-
United States	45,3	5	4,6	3,4	13
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	4,9	3,3	3,4	11,6

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.30: Virtual water content of primary energy from sugarbeet in the HEI-system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	$v_{green}{}^{b}$ $m^3/GJ\ HHV$	$v_{blue}{}^{c}$ $m^3/GJ\ HHV$	$v_{grey}{}^{d}$ $m^3/GJ\ HHV$	$v_{total}{}^{e}$ $m^3/GJ\ HHV$
Argentina	-	-	-	-	-
Australia	-	-	-	-	-
Austria	0,9	12,3	6,1	3,2	21,6
Belgium	1,9	20,1	9,4	3,2	32,7
Brazil	-	-	-	-	-
Burkina Faso	-	-	-	-	-
Canada	0,2	21	3,6	3,2	27,8
Chile	1	6,4	0,3	3,2	9,9
China	3,6	19,8	8,1	3,2	31,1
Colombia	-	-	-	-	-
Cuba	-	-	-	-	-
Czech Republic	1	16,9	6,3	3,2	26,4
Egypt	0,7	2,1	22,1	3,2	27,4
Ethiopia	-	-	-	-	-
France	10	14,1	6,1	3,2	23,4
Germany	8,4	17,5	6	3,2	26,7
Guatemala	-	-	-	-	-
Hungary	0,9	14,6	10,9	3,2	28,6
India	-	-	-	-	-
Indonesia	-	-	-	-	-
Iran	1,5	9,5	0,9	3,2	13,5
Italy	4,1	7,8	0,5	3,2	11,4
Japan	1,2	21,1	0	3,2	24,3
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-
Weighted average A-Z	-	15,5	6,5	3,2	25,2

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.31: Virtual water content of primary energy from sugarbeet in the HEI-system for 25 countries: L-Z

Country	Prod[a]	v_{green}[b]	v_{blue}[c]	v_{grey}[d]	v_{total}[e]
	$DM\ Mton/yr$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$
Latvia	0,1	28,9	11,5	3,2	43,6
Lithuania	0,3	22,4	7,2	3,2	32,8
Malaysia	-	-	-	-	-
Mali	-	-	-	-	-
Mexico	0	16,2	8,2	3,2	27,6
Netherlands	2,1	18	5,9	3,2	27,1
New Zealand	-	-	-	-	-
Nigeria	-	-	-	-	-
Pakistan	0	16,9	20,2	3,2	40,2
Philippines	-	-	-	-	-
Poland	4,3	17,5	6,6	3,2	27,2
Russian Federation	4,4	9,9	1,8	3,2	14,8
Slovakia	0,4	16,8	11	3,2	30,9
South Africa	-	-	-	-	-
Spain	2,6	11,2	9,3	3,2	23,6
Sudan	-	-	-	-	-
Sweden	0,8	16,4	11,3	3,2	30,9
Switzerland	0,4	23,7	1,1	3,2	28
Tanzania, United Republic of	-	-	-	-	-
Thailand	-	-	-	-	-
Turkey	-	-	-	-	-
Ukraine	4,8	17,6	7,8	3,2	28,6
United Kingdom	3,1	14,8	8,4	3,2	26,3
United States	8,9	19,4	9,3	3,2	31,9
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	15,5	6,5	3,2	25,2

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.32: Virtual water content of primary energy from sugarcane in the HEI-system for 25 countries: A-K

Country	Prod[a]	v_{green}[b]	v_{blue}[c]	v_{grey}[d]	v_{total}[e]
	$DM\ Mton/yr$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$
Argentina	-	-	-	-	-
Australia	16,8	5,8	8,7	2,9	17,3
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil	152	10,8	4,2	2,9	17,8
Burkina Faso	-	-	-	-	-
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China	35,6	9,5	2,7	2,9	15
Colombia	15,2	9,6	0,1	2,9	12,5
Cuba	15,7	9,6	4,7	2,9	17,1
Czech Republic	-	-	-	-	-
Egypt	6,7	1	16,9	2,9	20,7
Ethiopia	-	6,8	5	2,9	14,7
France	-	-	-	-	-
Germany	-	-	-	-	-
Guatemala	7,8	8,2	4,4	2,9	15,5
Hungary	-	-	-	-	-
India	129	5,6	9,9	2,9	18,3
Indonesia	11,5	15,4	2,8	2,9	21
Iran	1,1	2,5	13,9	2,9	19,3
Italy	-	-	-	-	-
Japan	0,7	9,7	0	2,9	12,5
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-
Weighted average A-Z	-	8,7	6,0	2,9	17,5

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.33: Virtual water content of primary energy from sugarcane in the HEI-system for 25 countries: L-Z

Country	Prod[a]	v_{green}[b]	v_{blue}[c]	v_{grey}[d]	v_{total}[e]
	$DM\ Mton/yr$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	0,7	16,7	0,9	2,9	20,4
Mali	-	-	-	-	-
Mexico	20,9	7,9	5,1	2,9	15,8
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	-	-	-	-	-
Pakistan	21,6	6,2	8,3	2,9	17,4
Philippines	11,7	10,9	2,5	2,9	16,3
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa	10	8,5	5,3	2,9	16,6
Spain	-	-	-	-	-
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania, United Republic of	0,6	6,5	9,6	2,9	18,9
Thailand	23,1	9,2	6,2	2,9	18,2
Turkey	-	-	-	-	-
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	14,1	11,2	7,4	2,9	21,5
Viet Nam	6,6	9,3	2,4	2,9	14,6
Weighted average A-Z	-	8,7	6,0	2,9	17,5

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.34: Virtual water content of primary energy from soy in the HEI-system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^{b}$ $m^3/GJ\ HHV$	${v_{blue}}^{c}$ $m^3/GJ\ HHV$	${v_{grey}}^{d}$ $m^3/GJ\ HHV$	${v_{total}}^{e}$ $m^3/GJ\ HHV$
Argentina	44,5	18,3	10,1	1,7	30,1
Australia	0,2	9,4	0	1,7	11
Austria	0,1	12,7	10,9	1,7	25,3
Belgium	-	-	-	-	-
Brazil	73,8	20,6	0	1,7	22,3
Burkina Faso	0	21,2	2,1	1,7	24,9
Canada	5,8	17,4	7	1,7	26,1
Chile	-	-	-	-	-
China	34,5	18,7	8,1	1,7	28,5
Colombia	0,1	21,9	0	1,7	23,5
Cuba	-	-	-	-	-
Czech Republic	0	18,5	9,7	1,7	29,8
Egypt	-	-	-	-	-
Ethiopia	0,1	20,5	5,7	1,7	27,9
France	0,6	12,5	9,9	1,7	24
Germany	0	15,1	11,6	1,7	28,4
Guatemala	0,1	41,3	0	1,7	43
Hungary	0,1	13,3	11,1	1,7	26,1
India	14,7	24,6	3,4	1,7	29,7
Indonesia	2,7	28,9	0	1,7	30,5
Iran	0,3	6,8	2,2	1,7	10,7
Italy	2,3	14,2	9	1,7	24,9
Japan	0,5	22,1	0,2	1,7	24
Kazakhstan	-	-	-	-	-
Korea, Republic of	0,3	26,3	1,3	1,7	29,3
Weighted average A-Z	-	19,5	6,8	1,7	28,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.35: Virtual water content of primary energy from soy in the HEI-system for 25 countries: L-Z

Country	Prod[a] $DM\ Mton/yr$	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	-	-	-	-	-
Mali	-	-	-	-	-
Mexico	0,3	14,8	14,8	1,7	31,3
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	0,9	16,6	7	1,7	25,2
Pakistan	0	17,8	0	1,7	19,4
Philippines	0	23,2	0	1,7	24,9
Poland	0	15,8	5,5	1,7	22,9
Russian Federation	0,7	13,5	15,4	1,7	30,5
Slovakia	0	16,1	11,8	1,7	29,5
South Africa	0,4	11,1	2,2	1,7	15
Spain	0	6,2	0	1,7	7,9
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland	0	28,4	1,6	1,7	31,7
Tanzania, United Republic of	0	14,6	7,5	1,7	23,8
Thailand	0,7	22,5	0,7	1,7	24,9
Turkey	0,1	9,8	12,6	1,7	24
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	172	19,2	9,1	1,7	29,9
Viet Nam	0,3	33,4	0	1,7	35,1
Weighted average A-Z	-	19,5	6,8	1,7	28,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.36: Virtual water content of primary energy from rape in the HEI-system for 25 countries: A-K

Country	Prod[a] *DM Mton/yr*	v_{green}[b] $m^3/GJ\ HHV$	v_{blue}[c] $m^3/GJ\ HHV$	v_{grey}[d] $m^3/GJ\ HHV$	v_{total}[e] $m^3/GJ\ HHV$
Argentina	0	10,4	7,8	11,5	29,7
Australia	3,9	10,9	2,6	11,5	25
Austria	0,3	9,8	6,8	11,5	28
Belgium	0	14,7	7	11,5	33,2
Brazil	0,1	24,6	0	11,5	36,1
Burkina Faso	-	-	-	-	-
Canada	16,2	10,9	11,1	11,5	33,4
Chile	0,1	5,2	0	11,5	16,7
China	23,4	13,1	0,9	11,5	25,4
Colombia	-	-	-	-	-
Cuba	-	-	-	-	-
Czech Republic	1,8	11	4,5	11,5	27
Egypt	-	-	-	-	-
Ethiopia	0	16,3	0,9	11,5	28,7
France	8,3	12,5	5,4	11,5	29,3
Germany	8,5	10,5	5	11,5	26,9
Guatemala	-	-	-	-	-
Hungary	0,4	10,5	8,1	11,5	30
India	12,5	11,5	10,2	11,5	33,2
Indonesia	-	-	-	-	-
Iran	-	-	-	-	-
Italy	0,1	13,5	7,4	11,5	32,3
Japan	0	15	0	11,5	26,4
Kazakhstan	-	-	-	-	-
Korea, Republic of	0	23,1	0,3	11,5	34,8
Weighted average A-Z	-	11,6	5,9	11,5	29,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.37: Virtual water content of primary energy from rape in the HEI-system for 25 countries: L-Z

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^b$ $m^3/GJ\ HHV$	${v_{blue}}^c$ $m^3/GJ\ HHV$	${v_{grey}}^d$ $m^3/GJ\ HHV$	${v_{total}}^e$ $m^3/GJ\ HHV$
Latvia	0	11,6	2,7	11,5	25,7
Lithuania	0,2	12,2	4,4	11,5	28
Malaysia	-	-	-	-	-
Mali	-	-	-	-	-
Mexico	0	16,2	0	11,5	27,6
Netherlands	0	12,3	4,4	11,5	28,2
New Zealand	0	10,3	0,6	11,5	22,4
Nigeria	-	-	-	-	-
Pakistan	0,7	7,9	10,2	11,5	29,5
Philippines	-	-	-	-	-
Poland	2,2	10,1	6,2	11,5	27,7
Russian Federation	0,3	11,7	11,5	11,5	34,6
Slovakia	0,4	11,1	7,5	11,5	30,1
South Africa	-	-	-	-	-
Spain	0,1	5,7	0,2	11,5	17,4
Sudan	-	-	-	-	-
Sweden	0,3	11,4	6,5	11,5	29,3
Switzerland	0,1	15,6	0,8	11,5	27,8
Tanzania, United Republic of	-	-	-	-	-
Thailand	-	-	-	-	-
Turkey	-	-	-	-	-
Ukraine	0,2	10,7	3,9	11,5	26
United Kingdom	3,3	10,4	7	11,5	28,8
United States	1,6	8,4	7,5	11,5	27,4
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	11,6	5,9	11,5	29,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.38: Virtual water content of primary energy from oil palm in the HEI-system for 25 countries: A-K

Country	Prod[a] $DM\ Mton/yr$	${v_{green}}^b$ $m^3/GJ\ HHV$	${v_{blue}}^c$ $m^3/GJ\ HHV$	${v_{grey}}^d$ $m^3/GJ\ HHV$	${v_{total}}^e$ $m^3/GJ\ HHV$
Argentina	-	-	-	-	-
Australia	-	-	-	-	-
Austria	-	-	-	-	-
Belgium	-	-	-	-	-
Brazil	0,1	15,1	5	1,9	22
Burkina Faso	-	-	-	-	-
Canada	-	-	-	-	-
Chile	-	-	-	-	-
China	0,3	7,3	10	1,9	19,2
Colombia	0,6	13,2	1,1	1,9	16,1
Cuba	-	-	-	-	-
Czech Republic	-	-	-	-	-
Egypt	-	-	-	-	-
Ethiopia	-	-	-	-	-
France	-	-	-	-	-
Germany	-	-	-	-	-
Guatemala	0,1	11	4,1	1,9	17
Hungary	-	-	-	-	-
India	-	-	-	-	-
Indonesia	8,5	17,5	2,4	1,9	21,8
Iran	-	-	-	-	-
Italy	-	-	-	-	-
Japan	-	-	-	-	-
Kazakhstan	-	-	-	-	-
Korea, Republic of	-	-	-	-	-
Weighted average A-Z	-	16,8	1,3	1,9	20,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

Table J.39: Virtual water content of primary energy from oil palm in the HEI-system for 25 countries: L-Z

Country	Prod[a]	v_{green}[b]	v_{blue}[c]	v_{grey}[d]	v_{total}[e]
	DM Mton/yr	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$	$m^3/GJ\ HHV$
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Malaysia	13,5	17,2	0	1,9	19
Mali	-	-	-	-	-
Mexico	0	8,1	5,8	1,9	15,8
Netherlands	-	-	-	-	-
New Zealand	-	-	-	-	-
Nigeria	-	-	-	-	-
Pakistan	-	-	-	-	-
Philippines	0,1	14,3	2,3	1,9	18,5
Poland	-	-	-	-	-
Russian Federation	-	-	-	-	-
Slovakia	-	-	-	-	-
South Africa	-	-	-	-	-
Spain	-	-	-	-	-
Sudan	-	-	-	-	-
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
Tanzania, United Republic of	0	12,8	6,3	1,9	21
Thailand	0,7	11,2	7,3	1,9	20,4
Turkey	-	-	-	-	-
Ukraine	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	-	-	-	-	-
Viet Nam	-	-	-	-	-
Weighted average A-Z	-	16,8	1,3	1,9	20,0

a) Average production of the primary crop in the period 1997-2001.
b) Green component of the virtual water content of primary energy.
c) Blue component of the virtual water content of primary energy.
d) Grey component of the virtual water content of primary energy.
e) Sum of the three components of the virtual water content of primary energy.

J.4 HEI system - secondary energy - first transformation

Table J.40: Virtual water content of liquid biofuels produced with first transformation of crops produced in the HEI-system for 25 countries: A-K ($m^3/GJ\ HHV$)

Country	ethanol					biodiesel		
	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Argentina	44,8	42,8	67,8	-	-	67,6	73,4	-
Australia	57,9	17,6	76,4	-	75,1	24,8	61,7	-
Austria	56,4	37,8	-	48,4	-	56,9	69,1	-
Belgium	82,3	108	-	73,4	-	-	81,9	-
Brazil	64	42,7	62,9	-	77,2	50,1	89,1	61,8
Burkina Faso	-	50	73,8	-	-	55,9	-	-
Canada	102	50,5	-	62,4	-	58,6	82,6	-
Chile	43,8	17,2	-	22,3	-	-	41,2	-
China	61,5	39,8	53,3	69,9	65,2	64,1	62,7	53,8
Colombia	60,9	33,6	49,9	-	54,4	52,9	-	45,2
Cuba	-	56,7	107	-	74,4	-	-	-
Czech Republic	68,7	45,1	-	59,2	-	67	66,6	-
Egypt	117	39,2	51,3	61,5	90	-	-	-
Ethiopia	95,5	38,1	59,6	-	63,8	62,8	71	-
France	84,4	46,8	-	52,5	-	54	72,4	-
Germany	71,7	46,8	-	59,9	-	63,8	66,5	-
Guatemala	106	60,2	102	-	67,2	96,7	-	47,6
Hungary	77,5	50,7	76,5	64,3	-	58,6	74,1	-
India	97	41,9	62	-	79,6	66,8	82,1	-
Indonesia	-	48,9	-	-	91,3	68,7	-	61
Iran	49	18,4	-	30,4	83,7	24	-	-
Italy	55,8	40,9	58,5	25,6	-	55,9	79,9	-
Japan	64,1	38	-	54,5	54,4	53,9	65,3	-
Kazakhstan	90	-	-	-	-	-	-	-
Korea, Republic of	75,7	42,8	107	-	-	65,9	86	-
Based on average crops	78	48	71	57	76	63	72	56

Table J.41: Virtual water content of liquid biofuels produced with first transformation of crops produced in the HEI-system for 25 countries: L-Z ($m^3/GJ\ HHV$)

Country	ethanol					biodiesel		
	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Latvia	70,7	-	-	97,9	-	-	63,5	-
Lithuania	67,2	-	-	73,6	-	-	69,2	-
Malaysia	-	-	-	-	88,6	-	-	53,3
Mali	136	51,3	72,9	-	-	-	-	-
Mexico	80,4	40,3	69,8	62	68,7	70,3	68,3	44,3
Netherlands	61,2	95,1	-	60,9	-	-	69,6	-
New Zealand	63,2	33	-	-	-	-	55,4	-
Nigeria	112	-	78,5	-	-	56,6	-	-
Pakistan	79,7	36,5	57	90,4	75,5	43,7	72,9	-
Philippines	-	51,9	-	-	70,6	55,9	-	51,8
Poland	61,8	74,9	-	61,1	-	51,6	68,5	-
Russian Federation	97,3	55,8	-	33,3	-	68,6	85,6	-
Slovakia	73,2	52	-	69,5	-	66,4	74,3	-
South Africa	84,2	53,9	62,5	-	72,2	33,6	-	-
Spain	52,1	47,8	32,2	53,1	-	17,7	42,9	-
Sudan	161	53,1	70,5	-	-	-	-	-
Sweden	69,6	-	-	69,4	-	-	72,3	-
Switzerland	62,8	44,8	-	62,8	-	71,3	68,7	-
Tanzania, United Republic of	136	44,1	74,7	-	82,1	53,5	-	58,8
Thailand	142	50,4	75,1	-	78,9	55,9	-	57,1
Turkey	78,4	41	-	-	-	54	-	-
Ukraine	77,4	53,1	70,7	64,3	-	-	64,2	-
United Kingdom	74,9	-	-	59,1	-	-	71,2	-
United States	88,2	54,8	79,8	71,6	93,3	67,2	67,7	-
Viet Nam	-	45,8	-	-	63,5	78,8	-	-
Based on average crops	78	48	71	57	76	63	72	56

J.5 Current system - secondary energy - second transformation

Table J.42: Virtual water content of liquid biofuels produced with second transformation of crops produced in the current system for 25 countries: A-K ($m^3/GJ\ HHV$)

	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Argentina	34,4	27,3	26,1	-	-	45,3	73,2	-
Australia	56,8	22,7	48,3	-	22,6	27,8	73,7	-
Austria	29,1	15	-	13,6	-	30,5	44,3	-
Belgium	32,1	12,8	-	18,3	-	-	41,6	-
Brazil	46,8	62,9	64	-	34,8	34,3	101	55,9
Burkina Faso	-	116	131	-	-	80,3	-	-
Canada	56,2	28,6	-	26,9	-	37,4	60,4	-
Chile	30,4	15,9	-	15,8	-	-	28,2	-
China	32,6	40,5	25	56,2	37,9	67,1	85,1	18,6
Colombia	65,2	78,3	30,6	-	24,3	40,2	-	28,4
Cuba	-	114	158	-	82,5	-	-	-
Czech Republic	45	19,3	-	22,2	-	54,1	46	-
Egypt	52,9	40	19,1	36,3	31,1	-	-	-
Ethiopia	113	85,3	75,1	-	19,9	28,6	167	-
France	24,1	21,7	13	13,8	-	25,8	46,4	-
Germany	37,5	20	-	22,1	-	37,2	38,6	-
Guatemala	102	122	105	-	21,6	38,7	-	27,8
Hungary	46,7	21,1	36,1	23,8	-	41,3	66,6	-
India	42,7	100	130	-	33,4	112	107	-
Indonesia	-	78,5	-	-	48,3	100	-	40,9
Iran	67,6	19,6	-	27,5	19,5	24,8	-	-
Italy	50,4	25,9	16,8	16,4	-	24,7	121	-
Japan	58,4	92,8	-	25,6	26,3	54,8	81,9	-
Kazakhstan	109	-	-	-	-	-	-	-
Korea, Republic of	77	58,9	77,5	-	-	88	118	-
Based on average crops	50	41	62	27	37	47	70	39

Table J.43: Virtual water content of liquid biofuels produced with second transformation of crops produced in the current system for 25 countries: L-Z ($m^3/GJ\ HHV$)

	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Latvia	55	-	-	36,8	-	61	71,5	-
Lithuania	49	-	-	32,4	-	-	70,5	-
Malaysia	-	85	-	-	42,5	220	-	38,9
Mali	98,2	114	78,8	-	-	-	-	-
Mexico	26,9	70,4	25,6	41,1	29,2	50,6	107	25,8
Netherlands	32	16,3	-	20,3	-	-	41,4	-
New Zealand	27,1	16,6	-	-	-	-	43	-
Nigeria	102	-	63,2	-	-	91,2	-	-
Pakistan	53,6	79,4	144	41,9	53,6	72,4	111	-
Philippines	-	115	-	-	38,5	66,1	-	47,9
Poland	51	19,1	-	31,6	-	259	50,1	-
Russian Federation	82	70,2	-	31,1	-	76,2	102	-
Slovakia	43	30,6	36,1	27,3	-	51,9	60,4	-
South Africa	55,3	60,3	23,1	-	33,1	37,2	-	-
Spain	47,5	19,6	11	21,5	-	17,8	41	-
Sudan	85,5	240	156	-	-	-	-	-
Sweden	30,9	-	-	21,4	-	-	49,7	-
Switzerland	41,5	23,8	-	21,7	-	34,4	51,7	-
Tanzania, United Republic of	104	203	83,2	-	20,4	177	-	42,3
Thailand	262	55,3	70,2	-	43,5	53,8	-	33,7
Turkey	85,1	34,5	-	-	-	25,6	-	-
Ukraine	49,7	44,4	67,8	59,7	-	-	99,8	-
United Kingdom	29,9	-	-	17	-	-	38,1	-
United States	72,1	29,4	30	31,7	33,8	43,4	67,3	-
Viet Nam	-	87,7	-	-	48,3	121	-	-
Based on average crops	50	41	62	27	37	47	70	39

Table J.44: Virtual water content of liquid biofuels produced with second transformation of trees produced in the current system ($m^3/GJ\ HHV$)

	eucalyptus	pine	poplar
Argentina	56	85	70
Australia	90	150	-
Belgium	-	88	62
Brazil	49	78	100
Chile	69	81	52
China	260	240	130
France	-	120	-
India	200	550	91
Indonesia	130	343	-
Iran	230	-	190
Italy	81	75	71
Lithuania	-	150	-
Netherlands	-	130	59
New Zealand	-	79	-
Philippines	-	210	-
Poland	-	130	76
Slovakia	-	270	140
South Africa	89	170	-
Sudan	180	-	-
Ukraine	-	-	106
United Kingdom	-	110	-
United States	-	300	-
Viet Nam	200	510	-
Based on median crops	107	140	83

J.6 HEI system - secondary energy - second transformation

Table J.45: Virtual water content of liquid biofuels produced with second transformation of crops produced in the HEI-system for 25 countries: A-K ($m^3/GJ\ HHV$)

	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Argentina	17	18	19	-	-	40	39	-
Australia	23	7	22	-	35	15	33	-
Austria	22	16	-	32	-	33	37	-
Belgium	32	44	-	48	-	-	44	-
Brazil	25	18	18	-	36	29	48	35
Burkina Faso	-	21	21	-	-	33	-	-
Canada	40	21	-	41	-	34	44	-
Chile	17	7	-	15	-	-	22	-
China	24	16	15	46	30	38	34	30
Colombia	24	14	14	-	25	31	-	25
Cuba	-	23	30	-	35	-	-	-
Czech Republic	27	19	-	39	-	39	36	-
Egypt	46	16	15	40	42	-	-	-
Ethiopia	37	16	17	-	30	37	38	-
France	33	19	-	34	-	32	39	-
Germany	28	19	-	39	-	38	36	-
Guatemala	41	25	29	-	31	57	-	27
Hungary	30	21	22	42	-	34	40	-
India	38	17	18	-	37	39	44	-
Indonesia	-	20	-	-	42	40	-	34
Iran	19	8	-	20	39	14	-	-
Italy	22	17	17	17	-	33	43	-
Japan	25	16	-	36	25	32	35	-
Kazakhstan	35	-	-	-	-	-	-	-
Korea, Republic of	29	18	30	-	-	39	46	-
Based on average crops	30	20	20	37	35	37	38	31

Table J.46: Virtual water content of liquid biofuels produced with second transformation of crops produced in the HEI-system for 25 countries: L-Z ($m^3/GJ\ HHV$)

	wheat	maize	sorghum	sugarbeet	sugarcane	soy	rape	oil palm
Latvia	28	-	-	64	-	-	34	-
Lithuania	26	-	-	48	-	-	37	-
Malaysia	-	-	-	-	41	-	-	30
Mali	53	21	21	-	-	-	-	-
Mexico	31	17	20	41	32	41	37	25
Netherlands	24	39	-	40	-	-	37	-
New Zealand	25	14	-	-	-	-	30	-
Nigeria	44	-	22	-	-	33	-	-
Pakistan	31	15	16	59	35	25	39	-
Philippines	-	21	-	-	33	33	-	29
Poland	24	31	-	40	-	30	37	-
Russian Federation	38	23	-	22	-	40	46	-
Slovakia	29	21	-	46	-	39	40	-
South Africa	33	22	18	-	34	20	-	-
Spain	20	20	9	35	-	10	23	-
Sudan	63	22	20	-	-	-	-	-
Sweden	27	-	-	45	-	-	39	-
Switzerland	24	18	-	41	-	42	37	-
Tanzania, United Republic of	53	18	21	-	38	31	-	33
Thailand	55	21	21	-	37	33	-	32
Turkey	31	17	-	-	-	32	-	-
Ukraine	30	22	20	42	-	-	34	-
United Kingdom	29	-	-	39	-	-	38	-
United States	34	23	23	47	43	40	36	-
Viet Nam	-	19	-	-	30	46	-	-
Based on average crops	30	20	20	37	35	37	38	31