Food Commodity Footprints

Global GHG footprints and water scarcity footprints in agriculture

Macro assessment of palm oil fruit, sugarcane, soybean, wheat, rice, maize, tea, coffee, potatoes, tomatoes, cocoa, coconut, banana, citrus fruits, pineapple, strawberry and apple

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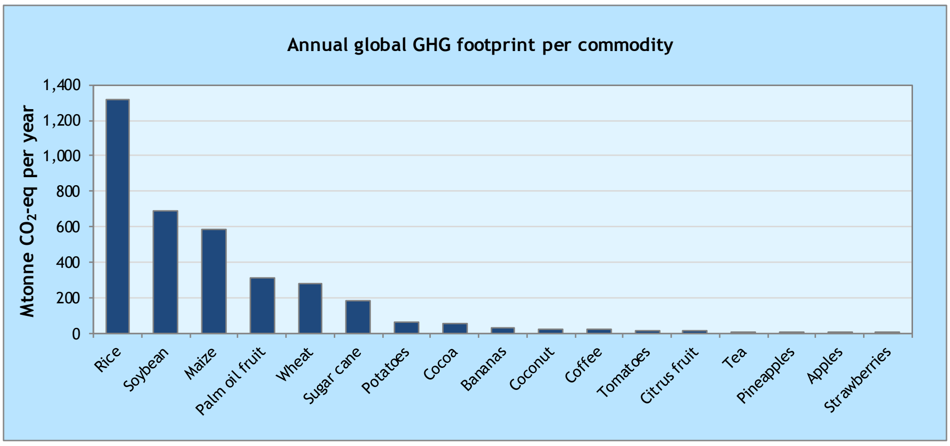
Highlights

Seventeen food commodities were included in this study. All aggregated results (also presented in these highlights) refer to these seventeen commodities. The six commodities with the highest global production rates are sugar cane, maize, wheat, rice, potatoes and soybeans (all included in this study). Along with these, another six commodities out of the top 18 in global production were included: palm oil fruit, tomatoes, citrus fruits, bananas, apple. Furthermore, the commodities coconut, pineapple, coffee, cocoa, tea, strawberries were included.

The total global GHG (greenhouse gas) footprint amounts to 3,6 Gigatonne CO_2 eq (Figure 1). Rice and soybean contribute most with respectively 37% and 19% of that number. Asia & Oceania is the region with the highest footprint: ~2 Gigatonne, over 50% of the total global GHG footprint.

Figure 1 Annual global GHG footprint per commodity. The total (for these 17 commodities) amounts to 3,6 Gigatonne CO_2 eq

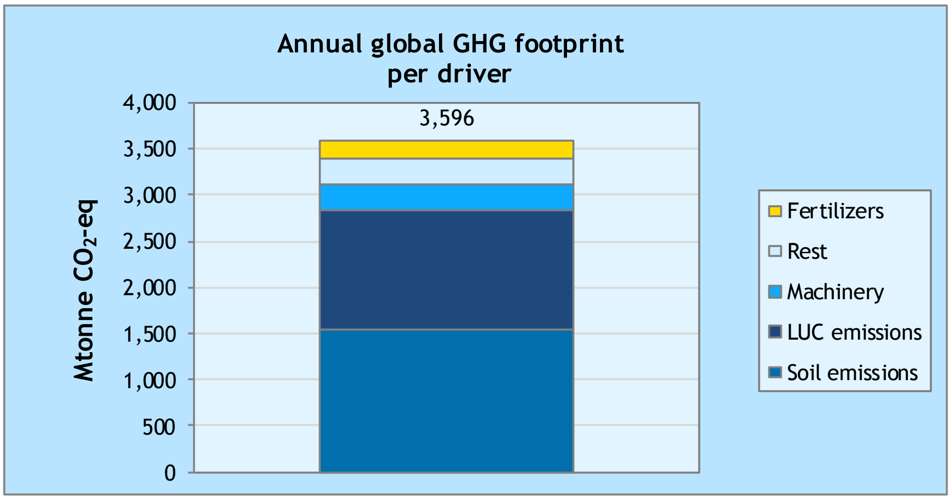


The region Asia & Oceania (see Annex A) is the region with the highest production (in Mtonne). Of the total global production (in tonnes), this region contributes 50%. Latin America, North America, Europe and Africa contribute respectively 25, 11, 9 and 5%. Asia & Oceania is also the region with the highest population: 60% of the global total population. Africa, Europe, Latin America and North America follow with respectively 15, 11, 9 and 5%.

Cereals account for 42% of the total global production. **Climate change will likely impact the production of cereals negatively on a global scale.** Lower latitude countries are more likely to experience a decrease in crop yields. Some higher latitude countries may experience an increase for some crops.

Soil emissions are the most important driver (Figure 2) for the GHG footprint. Soil emissions and LUC (land-use change) contribute respectively 42 and 36% to the total global GHG footprint. Machinery, fertilizers and rest contribute respectively 8, 6 and 8%. Where the area under cultivation is expanding, LUC is an issue. The emissions depend on the original land use: e.g. in case of transformation of (rain) forest, LUC emissions will be relatively high. Soil emissions are relatively high for rice (due to methane emissions): Soil emissions from rice production in Asia & Oceania account for 72% of regional soil emissions and for 45% of the total regional footprint.

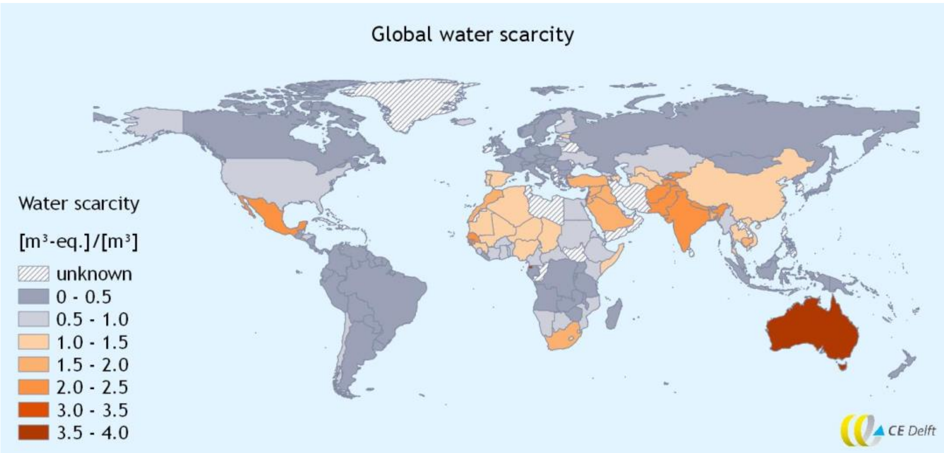
Figure 2 Annual global GHG footprint per driver



The commodity with the highest GHG footprint (per tonne) is cocoa from Asia & Oceania. Other commodities with high GHG footprints are cocoa from Africa, soybean and coconut from Latin America and coffee from Asia & Oceania. GHG footprints per tonne are high for stimulants (cocoa, coffee, tea). Due to increasing demands and low yields, LUC plays an important role in the GHG footprint of these commodities.

Asia & Oceania is the region with the highest irrigation water use (blue water) in agriculture: 541 km^3 for our seventeen commodities. Blue water use in Africa, North America, Latin America and Europe is respectively 54, 47, 29 and 22 km^3. **Asia & Oceania is also the region with the highest water scarcity indicator: 1.70 m^3 eq/m^3.** A water scarcity indicator of over 1 indicates water scarcity; consumption exceeds availability. Increasing water efficiency could help this region face the water scarcity it is already experiencing and which will likely increase in the future.

Figure 3 Global water scarcity (based on (Hoekstra, et al., 2012))



Cereals account for over 80% of the global water scarcity footprint (42% of production). Commodities with a relatively high water scarcity footprint are tea from Asia & Oceania and Latin America, wheat from Asia & Oceania and rice from all regions. Sugar cane has the highest total global production, but a relatively low GHG footprint and water scarcity footprint.

We refer to this report and the accompanying Excel workbook for the methodology and complete results (data and figures).

1 Introduction

Agriculture is a major emitter of greenhouse gases (GHGs), and a major user of water. Globally, this sector accounts for around 22-25% of anthropogenic emissions of greenhouse gases, including emissions caused by land use change (LUC) (IPCC, 2014), and for 70% of water withdrawals (FAO, 2012). To gather information to use in public campaigns, Oxfam has asked CE Delft to provide insight into the global GHG (greenhouse gas) footprints and water (scarcity) footprints of major food commodities, along with a regional differentiation (of five different continental regions).

1.1 Goal

Oxfam wants to offer consumers new insights in the climate change effects and the water effects of food commodities in the regions they grow.
They want to do this by linking the regional activities, which impact the environment (regional GHG footprint and water footprint), to the regions where the effects of e.g. climate change will be most noticed. Furthermore, Oxfam is looking for a story which will help consumers understand the magnitude of the issues. Therefore, the main research questions are:
1. What are the regional and global GHG footprints of major food commodities?
2. What are the regional and global water (scarcity) footprints of main food commodities?
3. What are the regions (and/or countries) and commodities most likely to be impacted by climate change?

The following commodities are included in the present study: palm oil fruit, sugar cane, soybean, wheat, rice, maize, tea, coffee, potatoes, tomatoes, cocoa, coconut and fruits (banana, citrus fruit, pineapple, strawberries and apple). Footprints are differentiated on a regional scale. Five regions are included (North America, Latin America, Africa, Europe and Asia including Oceania), together representing the total global production (see Annex A).

1.2 Structure of report and excel workbook

This report is accompanied by an Excel workbook in which all the data and results are included.

Table 1 Contents of excel workbook GHG footprints and water (scarcity) footprints

Worksheet	Content
Introduction	→ Short description of methodology and results included in the workbook.
Highlights - GHG footprints	→ Highlights related to the global, regional and commodity GHG footprints.
Highlights - water scarcity footprints	→ Highlights related to the global, regional and commodity water scarcity footprints.
Global footprints	→ Global production and GHG and water scarcity footprints per commodity, commodity type and driver.

Worksheet	Content
Regional footprints	→ Regional production and GHG and water scarcity footprints per commodity, commodity type, driver and region.
Seventeen commodity sheets (e.g. apple)	→ Commodity production, GHG footprint per tonne, hectare, region, all per driver. Water use (blue and green) per tonne and per region and the water scarcity footprint per tonne, hectare and region.
Background info	→ Background data and information on the Life Cycle Assessment (LCA) inventories used.
Five regional data sheets	→ Data per region on production per commodity per country.

Because of the broad scope of the study not all commodities will be elaborated on individually in this report. In this report the methods, data and databases used will be elaborated on in Chapter 2.

In Chapter 3 information about the effect of agriculture on climate change and of climate change on agriculture is presented. In Chapter 4 one commodity (soybeans) is elaborated on, in text and in figures. The data which these figures are based on (as well as the figures) are included in the Excel workbook. Chapter 5 and 6 will respectively elaborate on the regional and global GHG footprints and water footprints.

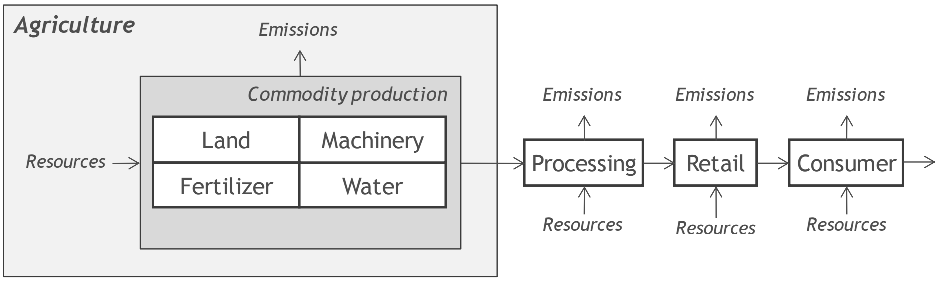
2 Method

In this chapter we elaborate on our methods and data used. We present the scope (Section 2.1), the regions (Section 2.2), the commodities (Section 2.3) and the data (Section 2.4).

2.1 Scope

The footprints presented in this report relate to the agricultural phase of the life cycle (see Figure 4). Processing, retail and subsequent phases are not included in our footprints, as is transport from the farm to subsequent locations.

Figure 4 Phases in the life cycle of food products - we focus on the agricultural phase



Several practices in the agricultural phase of food production have an impact on climate change. Included in the GHG footprints of the commodities presented in this report are:
- emissions related to land use change (LUC);
- emissions and energy use from machinery;
- emissions related to production of fertilizer;
- emissions related to use of manure and fertilizer (soil emissions).

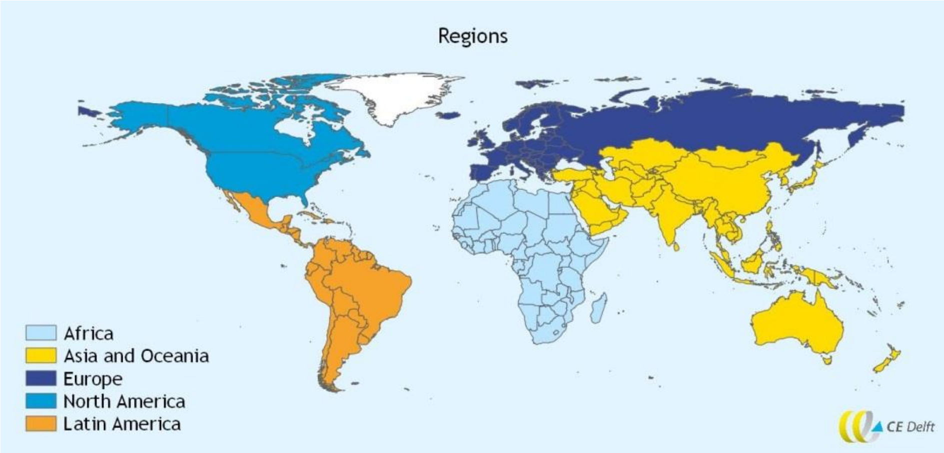
Inputs related to the water footprint are:
- blue water: water used in irrigation;
- green water: rain water.

The footprints are based on existing life cycle inventories. In Table 3 (on Page 19) the choices made regarding databases and inventories are given for all commodities.

2.2 Regions

We follow the FAO arrangement of countries into regions, and divided the world into 5 main regions: Africa, Asia & Oceania, Europe, Latin America and North America. These are shown in Figure 5 (see Annex A for country lists per region). In five 'region sheets' in the excel file, the production quantities per country for each commodity are given.

Figure 5 **Regions**



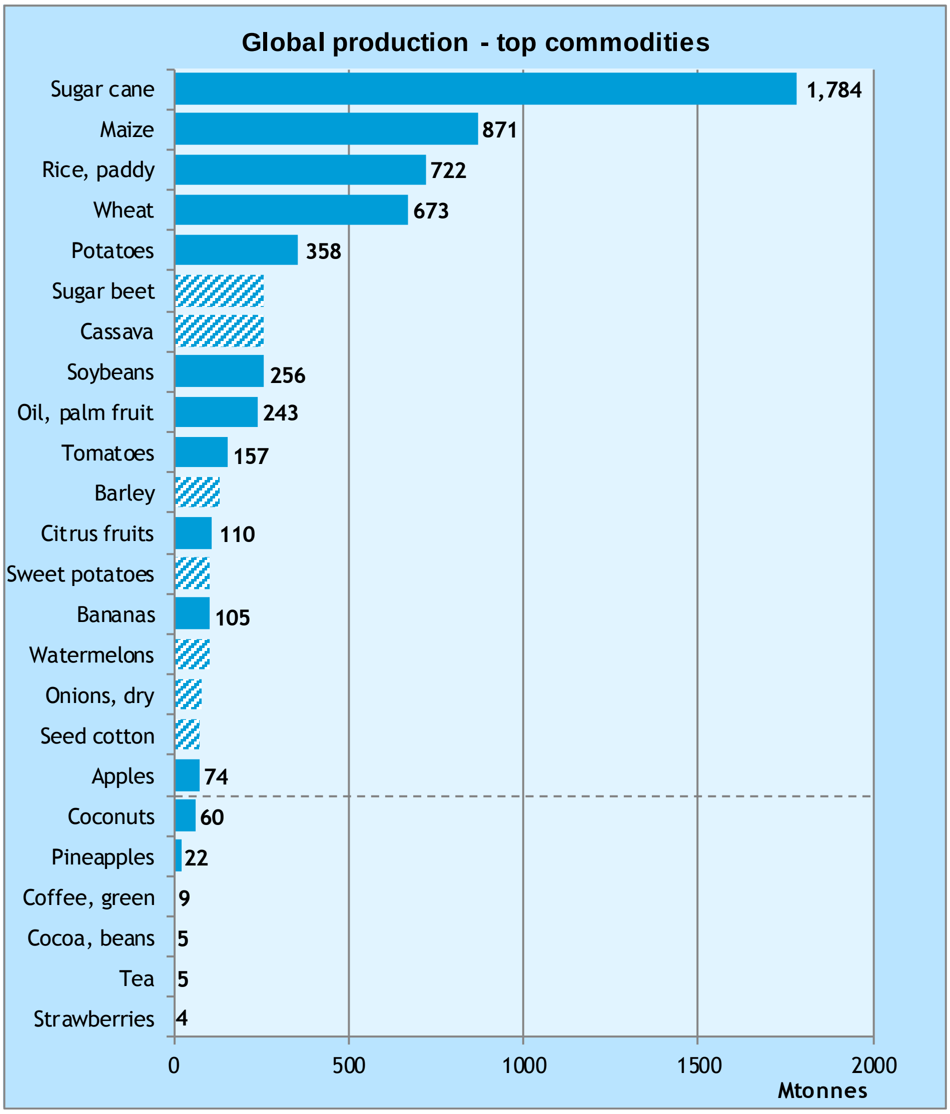
2.3 Commodities

Oxfam is interested in a variety of commodities. Most of these commodities are in the top-20 when one looks at the global production quantities. Figure 6 shows the top-18 commodities, eleven of which are included in this study. These commodities all account for over 1% of total global food production. Commodities included in this study are shown in blue in Figure 6.

Six commodities, in which Oxfam expressed a specific interest and which were incorporated in this study, fall outside of this range. Three of those belong to the ‘food’ group ‘stimulants’: coffee, tea and cocoa. It is therefore not surprising that production quantities are rather low. These commodities are also included in Figure 6.

All the commodities included in this study are food commodities, but are or can be used for other purposes, such as feed or biofuels. We take total global production into account, including the part used for purposes other than food.

Figure 6 Global production of top-18 commodities (all contribute over 1% of total global food production) + remaining commodities included in this study (under the dotted line)



Note: The commodities included in this study are shown in blue, the diagonally striped pattern indicates that the commodities are not included in this study.
Citrus fruits represent the aggregated total of oranges, lemons, limes, tangerines, mandarins and clementine's.

2.4 Data

In this section we elaborate on the data we used to calculate the GHG footprints and the water scarcity footprints. First we elaborate on the basis for the regional differentiation. Second, we elaborate on all the data and methods we used to make these differentiations.

2.4.1 Regional differentiation

Datasets are representative for production in a certain country, or for a certain type of production (e.g. intensive). Agricultural practices differ in different parts of the world. Furthermore, regional circumstances differ. This results in differences in yields and in GHG footprint and water (scarcity) footprint between regions, for the same commodity. Therefore, we differentiated on a (limited) number of important aspects.

Two factors important to the GHG footprint differ significantly between regions, and were therefore use to make a regional differentiation:

1. Yields (tonne of product per hectare).
2. Land use change emissions (hectares converted from one type of land use to another, with related GHG emissions).

There are also two factors related to the water scarcity footprint, which differ significantly between regions:

1. Water use (blue water use, i.e. water used in irrigation).
2. Water scarcity index (water use to availability ratio).

Yields are reported by the FAO on a country level. LUC-emissions are calculated by the Direct Land Use Change Emissions Tool (Blonk Consultants, 2013) on a country level.
To limit extensive elaboration on a country level, the regional average will be based on the contribution of the countries whose production add up to more than 80% of the regional total. Elaboration on the methods used is given in Annex B. Data and methods we used are elaborated on in the following sections.

2.4.2 Production and yield: FAO-data

Production data are gathered from the database of the Food and Agriculture Organization of the United Nations (FAO, 2014). The three-year (2010-2012, most recent years available) average yield and production will be used to even out ‘bad’ or ‘good’ years. This yields a more representative picture of current production. Five regions will be included (North America, Latin America, Africa, Europe and Asia including Oceania), together representing the total global production (see Annex A).

2.4.3 GHG emissions: drivers, data and method

Drivers

The GHG footprint consists of different types of emissions, which we call drivers. Together, the drivers encompass the complete footprint (for the agricultural phase of the life cycle). The drivers we distinguish are:

1. LUC emissions – emissions related to land-use change.
2. Soil emissions – emissions from the soil, related to agricultural practices. These are emissions due to use of fertilizer and manure, emissions related to crop residues, and emissions related to irrigation practice (in the case of rice). Emissions from peat soils are included for palm oil fruit cultivation.
3. Machinery – emissions associated with the energy input (mostly diesel).
4. Fertilizers – emissions associated to production of the different synthetic fertilizer inputs. There are no emissions associated to ‘production’ of manure.
5. Rest – emissions associated with production of agrochemicals other than fertilizer (e.g. pesticides), other materials and in some cases electricity use.

Use of pesticides does not contribute to the GHG footprint. These emissions are toxic, and contribute to other environmental impact categories: toxicity and eco-toxicity. These environmental impact categories are not included in this study. The GHG emissions related to production of pesticides are included in ‘rest’.

Data: LUC emissions (CO_2)
A transformation from one type of land use to another means a change in carbon stock. Such land transformation is called land use change (LUC). When for example forest is converted to agricultural land, the carbon stock of the land is reduced and is emitted as CO_2. The Direct Land Use Change Assessment Tool (Blonk Consultants, 2013) calculates these emissions for a specific country and crop combination. This methodology includes land use change over the past 20 years. The calculations include aboveground carbon stock and soil organic carbon. This tool can be used for assessments which conform to PAS 2050-1, the GHG Protocol, ENVIFOOD Protocol and others.

We used the 'country known; land use unknown' feature, which means that emissions are estimated based on reference scenarios for previous land use and data on land use expansions from FAOSTAT. We used the weighted average GHG emissions from land use change in our calculations (required by the Food SCP method). The carbon stock differs for different land use types (i.e. forest, grassland, perennial cropland and annual cropland). In the weighted average these differences are incorporated.

Land use change emissions can also be negative; instead of a carbon emissions there is a carbon sink. Land use change from agricultural land to forest cannot, however, be attributed to an agricultural product. Therefore, if the tool yields a negative value, this is set to zero (in the tool). In those cases we also assumed the LUC-emission to be zero.

ILUC
We looked at total global production of the food commodities, including production used for food, feed, seed and other utilities. Just because these are food commodities, does not mean they are not used for other purposes, such as biofuels. The land use change emissions included in this study are the emissions related to direct land use change by the commodities included in the study.

Indirect land use change (ILUC) is mainly used as a concept for crops used for novel purposes, when the final product is used to substitute fossil fuel based products (biofuels for transport, bioenergy and biochemistry). Indirect land use change occurs when for example additional production of sugar cane in Brazil, on land formerly used to produce soybean, causes the soybean farmers to search for other production locations and change forest into agricultural land. One could say that in this case the biofuel producers using sugar cane are partially responsible for the deforestation caused by the soybean producers.

One of the reasons to shift from fossil based to a biobased economy, are environmental considerations. Governments encourage use of such biobased products by obligating its use or by giving subsidies. For example, the European biofuel obligations are meant to lower the GHG emissions of the transport sector. In order to assess the environmental sustainability, emissions related to direct and indirect land use change should be taken into account for these purposes. Additional demand (such as for biofuels) leads to additional production of crops, and emissions related to direct land use change and possibly indirect land use change. The biofuels sector is held responsible for this with the ILUC concept.

ILUC is not explicitly calculated in this study. Calculating ILUC means allocating part of commodity B's LUC to commodity A if A forces B to shift location. We take total global production into account for seventeen important commodities, including use for purposes such as biofuels. Land use change emissions were calculated for the total production quantity. Therefore, the

LUC calculations include a direct part and an indirect part. Here, the emissions are averaged out, and the ILUC effects linked to the interaction between our seventeen commodities, are included.

Part of the ILUC related to the novel purposes for the food commodities presented here is not included: that is the part which causes commodities other than the ones presented here to change location. Those can be food commodities, but also grasslands used to feed cattle or forestry (wood). For example: if pasture is converted to agricultural area, the cattle farmers will need to find other resources to feed their cattle.

Attributing LUC (both direct and indirect) to a certain sector means that the responsibility for the increase in agricultural area is linked those sectors according to their increase in production. The non-conventional sectors grow faster than the food-sector. When ILUC would be explicitly attributed to a certain sector, it would mean that emissions associated to land use change (both direct and indirect) would be higher than the emissions presented here (per tonne) for the non-conventional purposes, and a little lower for the production used for conventional purposes.

Data: other emissions (N_2O, CH_4 and CO_2)
The main drivers for GHG emissions, other than LUC emissions, are production of fertilizer, the soil emissions related to use of fertilizer and manure, and use of machinery. Our assessment of the GHG footprint is based on existing life cycle inventories. These important aspects are included in those inventories. Table 3 shows which inventories were chosen to represent which regions, and which additional, commodity specific, adjustments were made to get a representative regional average.

Method: IPCC 2013 GWP 100a
To calculate the GHG footprint, we use the method developed by the International Panel on Climate Change (IPCC): IPCC 2013 GWP 100a.
This method contains the latest characterisation factors (kg CO_2 eq per kg of emission X), for a timeframe of 100 years. This is the most commonly used method for calculating GHG footprints.

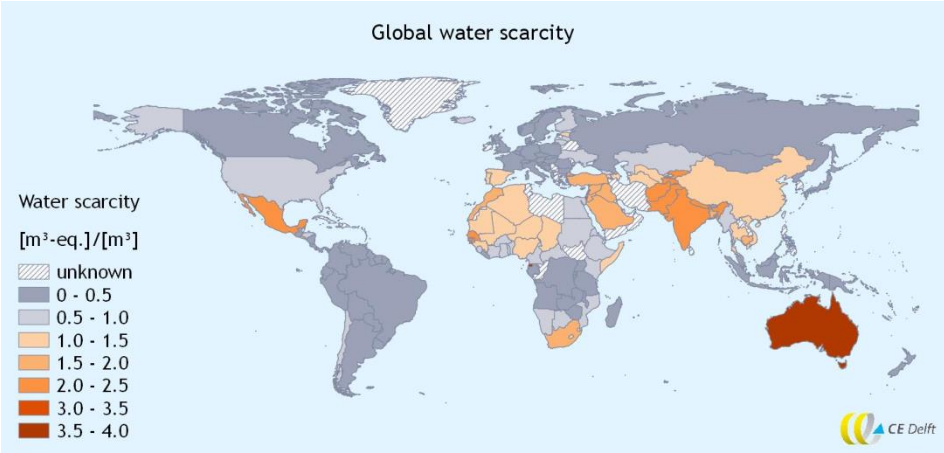
2.4.4 Water scarcity: data and method

Two additional datasets were needed to calculate water scarcity footprints: water used in irrigation (blue water) and water scarcity indicators which define a consumption-to-availability ratio.

The Water Footprint Network has a dataset available which includes the water use in agriculture for many commodities and many countries (Mekonnen & Hoekstra, 2010). They have modelled the green, blue and grey water use of crops (and crop products). Blue water use refers to water used in irrigation (surface and groundwater). Green water use refers to rainwater. Grey water refers to the freshwater needed for uptake of pollutants to an acceptable quality level. We will focus on blue water and green water. Water use for processes other than irrigation is also included in the inventories (in the background data). This usually contributes little to the water scarcity footprint.

Water availability is limited and the availability differs per country. When consumption exceeds availability, there is water scarcity. The threshold for water scarcity is when over 20% of total runoff is depleted (Mekonnen & Hoekstra, 2010). Exceeding this threshold means that environmental flow requirements probably cannot be met. A water scarcity indicator refers to the fraction between consumed water and available water. An analysis of 405 river basins, covering 69% of global runoff and 75% of the irrigated area, yielded water scarcity indicators for many countries on a global scale (see Figure 7, based on (Hoekstra, et al., 2012)). This method is currently available for Simapro (life cycle software) which makes it possible to calculate water scarcity footprints in life cycle assessments. The water scarcity indicator is available on a country level, for many countries, as shown in Figure 7. If the water scarcity indicator is higher than one, consumption exceeds availability. Regional averages are also included in the method.

Figure 7 Global water scarcity indicator



Source of data: (Hoekstra, et al., 2012).

To quantify regional water stress footprints, we used the regional average water scarcity indicators as defined in this method. These regional average water scarcity indicators are listed in Table 2.

Table 2 Water scarcity indicators

Region	Region and regional code (Hoekstra, et al., 2012)	Water scarcity indicator (m^3/m^3)
Africa	Africa (RAF)	0.98
Asia & Oceania	Asia and the Pacific (RAS)	1.70
Europe	Europe (RER)	0.59
North America	North America (RNA)	0.86
Latin America	Latin America and the Caribbean (RLA)	0.85

A higher water scarcity indicator means higher water scarcity. When the indicator is higher than one, consumption exceeds availability.

Water use in other processes

Water is also used in processes other than irrigation, for example in electricity production. This is taken into account in the water scarcity footprints. In most cases, water used in irrigation exceeds water used in other processes by far. This is not the case when irrigation water use is zero or very limited. Therefore, it is possible to get a positive water scarcity footprint even though irrigation water use is zero.

2.4.5 Inventory (life cycle) data

Different databases are available which include life cycle data for food commodities. Not all commodities included in this study are available within one single database. Furthermore, quite often data are only available for a few countries, in only one or two regions. Therefore, data from different databases were used, and adjustments were made to regionally differentiate the inventories.

We followed a few 'rules' in making decisions concerning which database to use:

1. Databases for life cycle inventories, in order of preference:
   a Agri-footprint (Blonk Consultants, 2014): this database is quite extensive. It includes inventories for a number of commodities, quite often for a number of countries per commodity. The countries are usually the most relevant based on production volumes. It is the most up-to-date database, 2014. The contribution of different factors (e.g. machinery) is given. For numerous commodities, inventories are given for different countries.
   b Ecoinvent 3: this database is also quite up-to-date (updated in 2013) and comprises several countries for a number of commodities. In some cases, Ecoinvent inventories are less elaborate than the Agri-footprint inventories, for example omitting the soil emissions. In other cases, they are more elaborate, for example specifying use of machinery into different types (energy for irrigation, energy for tillage). Furthermore, a 'rest of world' inventory is given for a number of commodities, which can serve as a proxy for regions without a corresponding country inventory. Like the Agri-footprint database, the contribution of different factors is given.
   c ESU-services (ESU-services, 2014): For some commodities no inventories are given in the Agri-footprint and the Ecoinvent databases. In those cases inventories were obtained from ESU-services. Because of financial constraints, inventories were bought which comprise the inventory in pressure factors (e.g. emission of SO_2 or PM_{10}) not the processes which are related to these pressure factors (e.g. use of machinery). LUC emissions are included and can easily be distinguished. The share of different drivers can therefore only be given for 'LUC emissions' and 'rest'.

   The system boundaries for all these inventories are from farm to farm gate, including fertilizer use and diesel use for field management. Sometimes the inventories include a storage period (electricity for cooling). This was excluded from the inventory for the present analyses, harmonize the inventories.
2. If multiple life cycle inventories are available for a commodity within one database (all choices regarding inventory per region and commodity are given in Table 3):
   a Match countries to regions. For example, the inventory for sugar cane in the US can serve as the proxy for production of sugar cane in North America. If multiple country inventories are available for one region (e.g. palm oil for Malaysia and Indonesia) the country inventory which represents the largest share of production in the region is chosen.
   b In case no country inventory is available for a certain region, an inventory from another country is used as a proxy in case the level of development and climate conditions are similar. When Ecoinvent 3 is chosen for a certain commodity, an inventory which represents a global average is used in case no country inventory is available for a certain region. In case no global average or clear proxy is available, an inventory which most closely represents the average value of the available inventories is chosen. If no such inventory is available, a

check is done to determine a limited number of distinguishing inputs to be averaged, to create an average inventory.

3. Preferably:
   a One database per commodity. Data from different databases are not always comparable, for example because different reference years are used.
4. Allocation to by-products: By-products may be formed in the agricultural phase, e.g. wheat straw, or in subsequent phases (during processing). In case numerous products are produced in the agricultural phase, we allocate part of the impact to the by-product. We focus on the impact of commodities up to the farm gate. In this study this is only an issue for wheat; wheat straw is also produced in the agricultural phase. Part of the impact is allocated to the straw. In case by-products are produced in later phases (processing), we do not allocate part of the impact of the environmental phase to such products.

The databases do not all have the same scope. The main difference is the inclusion of land use change emissions (LUC emissions) in the Agri-footprint database. For our calculation this is not a problem: we incorporate the LUC emissions calculated by the Direct Land Use Change Emissions Tool (see Paragraph 2.4.3) and add these in case they are not included in the inventory. This means that for all commodities in all regions LUC emissions are included in the inventory.

2.5 General limitations

As with any study which presents figures for (large) regions and on a global scale, this study has its limitations. The most important general limitations are described below.

- We present regional averages, based on existing life cycle inventories. For the most important factors, we made adjustments for the different regions. This means:
  - The regional commodity footprints cannot be used to say something about individual countries. Yields, input factors (fertilizer, manure, pesticides), water scarcity, etc., differ between countries.
  - The regional footprints (totals per commodity) are an indication. We differentiated on the most important issues, further differentiation/detailing is always possible.
  - We did not differentiate on fertilizer use, 'rest' (mainly pesticide use), and in most cases soil emissions. Therefore, the uncertainty regarding the results for these factors is larger than the uncertainty regarding LUC and water use. Two exceptions were made in which the soil emissions were regionally differentiated, because of their relative importance:
    - Methane emissions from rice cultivation; these are the most important contributor to global soil emissions;
    - CO_2 emissions from peat soils from palm oil fruit cultivation; these are an important contributor to the relatively high GHG footprint (compared to the other regions) of palm oil fruit cultivated in Asia & Oceania. Peat soils are common in Indonesia and Malaysia, which cover over 94% of regional production, and around 90% of global production.
- For the regional water scarcity footprints, regionally averaged values for water scarcity were used. Presenting regional data gives an indication of relative water scarcity (one region compared with another). Water scarcity is, however, a very regional/local issue, and should be addressed as such.

Just because Europe has a relatively low water scarcity indicator, does not mean water scarcity is not an issue regionally/locally.

- Global totals only take the 17 commodities into account which were included in this study (which do cover a substantial share of agricultural production). Conclusions based on these figures should take that into account.
- Production used for other purposes than food and feed is taken into account. LUC is averaged out over the total global production (regionally, per commodity). ILUC is not taken into account explicitly, but is implicitly included in the LUC calculations. The LUC results presented include both direct land use change and indirect land use change. ILUC is partially excluded; in those cases when non-conventional use of food commodities (such as biofuels) causes commodities other than the ones assessed in our study to change location (see Section 2.4.3).
- Certain issues are excluded. Known excluded issues are emissions from organic peat soils in the LUC calculations because of lack of data (although emission of CO_2 from peat soils is included in the palm oil inventory), and burning of sugar cane stalks before harvest.

Table 3 **Commodities (in alphabetical order) and corresponding life cycle databases used as a basis for the regional inventory**

Commodity	Data-base	Basis for inventory per region	Rationale
Apples	EI3	All regions: Apple {GLO}	Not available in the Agri-footprint database. This dataset represents apple production according to the Integrated Production standard in Switzerland. Well representative for production in industrialized countries. Life cycle: from maintenance of the orchards after harvest of the previous crop to harvest. Storage (5 months) was excluded from the inventory. Data is representative for productions in industrialized countries. The inventory will be used as a proxy for all regions; data will be differentiated on with yield and LUC-factors.
Bananas	EI3	All regions: Banana {GLO}	Not available in the Agri-footprint database. Data is well representative for conventional production in the main producing countries. Life cycle: from maintenance of the orchards after harvest of the previous crop to harvest. Storage (0.9 months) was excluded from the inventory.
Citrus fruits	EI3	All regions: Citrus {GLO}	Not available in the Agri-footprint database. Data is well representative for conventional production in the main producing countries. Life cycle: from maintenance of the orchards after harvest of the previous crop to harvest. Storage (2.1 months) was excluded from the inventory.
Cocoa	ESU	All regions: Cocoa, global average	Not available in either the Agri-footprint database or the Ecoinvent database. The inventory represents cultivation of cocoa tress with little mechanisation. The life cycle includes inputs of fertiliser, pesticides, water and energy. Harvesting, fermentation and drying is included (takes place at the farm).
Coconuts	AF	AFR: Coconut, at farm/PH AO: Coconut, at farm/ID LA: Coconut, at farm/PH EU and NA: no production	Inventories represent the average yearly production on a hectare on a typical farm in Indonesia (ID), India (IN) and the Philippines (PH). Disregarding LUC emissions, the GHG footprint of coconut in the three countries for which an inventory is available (Indonesia, India and the Philippines) are almost equal. The inventory which represents production in the Philippines approximates the average footprint (of the three). Therefore, this inventory was used for the other regions.
Coffee	ESU	All regions: Coffee, BR	Not available in either the Agri-footprint database or the Ecoinvent database. The inventory represents the cultivation of coffee trees with little mechanisation, in Brazil. The life cycle includes inputs of fertiliser and pesticides, and emission of nutrients and heavy metals.
Maize	AF	AFR: Maize, at farm/DE AO: Maize, at farm/DE EUR: Maize, at farm/FR NA: Maize, at farm/US LA: Maize, at farm/BR	Inventories represent the average yearly production on a hectare on a typical farm in the United States (US), Brazil (BR), France (FR) and Germany (DE). The main difference between the country inventories are the LUC emissions. For Africa and Asia & Oceania the inventory most closely representing the average of available inventories was chosen; Maize, at farm/DE (corresponds to average and to the Ecoinvent 'rest of world' inventory within a 5% margin). For Africa, Asia & Oceania and for Europe, the electricity mix was changed to represent the region; to a 'rest of world average[1] for Africa and Asia & Oceania and to a European average[2] for Europe.

[1] Inventory: Electricity, low voltage {RoW}|market for|Alloc Def.

[2] Inventory: Electricity, low voltage, production RER, at grid.

Commodity	Data-base	Basis for inventory per region	Rationale
Palm oil (fruit)	AF	AFR, AO and LA: Oil palm fruit bunch, at farm/MY For emission of CO_2 from peat soil: AO: weighted average of ID and MY AFR, LA: no emissions from peat soils EUR and NA: no production	Inventories represent the average yearly production on a hectare on a typical farm in Indonesia (ID) and Malaysia (MY). In Asia & Oceania, Indonesia covers 54% of production and Malaysia 41%. The GHG footprint for production in these countries differs significantly; excluding LUC around 0,9 kg CO_2 eq/kg in ID and 0,4 kg CO_2 eq per kg in MY. This difference is caused by the difference in area under harvest on peat soils, from which CO_2 is emitted, coupled to a higher yield in Malaysia. The emission factor in the Agri-footprint database was updated for this study, in cooperation with Blonk Consultants. They will include the updated emission factor in the update of their database which is scheduled to be released in the fall of 2015. The emission factor used is 20 ton C per hectare per year for cultivation in (sub)tropical regions on peat soils (or ~73 ton CO_2 per hectare per year) (IPCC, 2006). Emission of CO_2 from cultivation on peat soils was assumed to be 0 in Latin America and Africa, were peat soils are not as prevalent. See also Annex C.
Pineapple	EI3	All regions: Pineapple {GLO}	Not available in Agri-footprint database. Dataset represents pineapple production. Life cycle: from maintenance of the orchards after harvest of the previous crop to harvest. Storage (0.6 months) was excluded from the inventory.
Potatoes	AF	All regions: Starch potato, at farm/NL	Only two inventories are available in the Agri-footprint database (for Germany and The Netherlands). The latter was used and represents the average yearly production on a hectare on a typical farm in The Netherlands. The inventories for Germany and the Netherlands have comparable GHG footprints. In the Ecoinvent database inventories are given for the US and the 'rest of world', however, these show footprints that are almost twice as high as the footprints modelled in the Agri-footprint database (198 g CO_2 eq/kg). A quick internet search shows the Dutch inventory to be a reasonable average (113 g CO_2 eq/kg; which fits within the range of 80-160 g CO_2 eq/kg given by (Röös, 2013)).
Rice	AF	All regions: Rice, at farm/CN	Only rice production in China is available in the Agri-footprint database. Emission of methane and CO_2 depends on growing conditions. We use the IPCC emission factors and rules to make allowances for different growing conditions in different regions, see Annex C. Emission factors per country were obtained from (FAO, 2014).
Soybean	AF	AFR: Soybean, at farm/BR AO: Soybean, at farm/BR EUR: Soybean, at farm/US NA: Soybean, at farm/US LA: Soybean, at farm/BR	Inventories represent the average yearly production on a hectare on a typical farm in Brazil (BR), Argentina (AR) and the United States (US). These are the only inventories available in the Agri-footprint database. The main factor influencing the GHG footprint are the LUC emissions (90% of GHG footprint in AR and BR). When excluding LUC emissions, the US GHG footprint is only 6% lower than the BR GHG footprint (BR and AR are comparable). The US inventory was chosen to represent European production, and the BR inventory to represent Africa and Asia & Oceania.
Strawberries	EI3	All regions: Strawberry {GLO}	Not available in Agri-footprint database. No inventories are available for different countries in Ecoinvent. Dataset represents field production of strawberry. Life cycle: from plantation to harvest. Storage (0.2 months) was excluded from the inventory.
Sugar cane	AF	AFR: Sugar cane, at farm/SD AO: Sugar cane, at farm/IN EUR: Sugar cane, at farm/US NA: Sugar cane, at farm/US LA: Sugar cane, at farm/BR	Inventories represent the average yearly production on a hectare on a typical farm in Sudan (SD), India (IN), the United States (US) and Brazil (BR). The US inventory was chosen to represent European production because of the similar level of development and geographical characteristics and because it approximates the average of the available inventories (GHG footprint of within 6% of unweighted average). Burning of sugar cane stalks prior to harvest is not included in the GHG footprint.
Tea	ESU	All regions: Tea, at field, IN	Not available in either the Agri-footprint database or the Ecoinvent database. The life cycle includes production and application of fertilizers. The inventory represents conventional agriculture in India.

Commodity	Data-base	Basis for inventory per region	Rationale
Tomatoes	EI3	Basis for all regions: Tomato {GLO} AFR, AO, NA, LA: Tomato {GLO} without heat for greenhouses. EUR: weighted average, including heat for greenhouses for the Dutch share in production.	Not available in Agri-footprint database. Life cycle: from seedling production to harvest. Storage (0.5 months) was excluded. Energy for greenhouses is included in de the database. Energy for heat contributes around 80% of the total score. Therefore, we excluded this factor for regions were greenhouse production is not the predominant production method. Open field yields can amount to 100-120 tonnes/ha, yields in greenhouses can amount to up to 500 tonne/ha (Naandanjain Irrigation, 2012). Only in the Netherlands does the yield exceed the maximum open field yield: 480 tonne/ha. In all other countries in the 80% range, yields are lower than 85 tonne/ha (the yield in the US, second highest yield after the Netherlands). The GHG footprint without heat was checked against other LCA results and found to correspond to open field results (Theurl, et al., 2014). For Europe, heat and electricity use was included for the share of the Netherlands.
Wheat	AF	All regions: Wheat grain, at farm/FR	Only inventories for European countries are included in the Agri-footprint database. The smallest GHG footprint is around 20% lower than the highest footprint. France is the country with the highest wheat production in Europe and also the inventory which approaches the average of the available inventories best. It will therefore be used as a basis for all regions. The allocation factors of the impact to wheat grain and wheat straw for France will be used. These allocation factors differ by very small amounts in the EU (20,86%-21,58% of the impact is allocated to straw). France allocates the highest fraction of the impact to straw. It is possible that straw prices, compared to wheat prices, are lower in other regions (with less animal husbandry for instance). We may therefore underestimate the impacts of wheat grain in regions other than Europe, but price data on a regional scale are not available. Furthermore, prices and purchasing power parity fluctuate substantially between years and between countries, which makes it tricky to define regional allocation factors.

Databases: AF = Agri-footprint; EI3 = Ecoinvent 3; ESU = ESU services.

Regions: AFR = Africa; EUR = Europe; NA = North America; LA = Latin America; AO = Asia & Oceania.

3 Climate change and agriculture

In this chapter we discuss the contribution of agriculture to climate change (Section 3.1), the effects of climate change on agriculture (Section 3.2 and 3.3), and eight interesting campaigns/climate maps which may inspire Oxfam in thinking about how they want to present information (Section 3.4).

3.1 Effects of agriculture on climate change

When discussing greenhouse gas emissions (GHGs) in agriculture, it is useful to distinguish between CO_2 emissions and non-CO_2 GHG emissions (such as CH_4 and N_2O). The reason is that these are associated with different processes.

CH_4 and N_2O are usually emitted in smaller quantities, but the global warming potential is much higher. The characterisation factors for the three most important GHGs are listed in Table 4.

Table 4 **Global Warming Potentials (in CO_2 eq)**

	Global Warming Potential (GWP) in CO_2 eq
CO_2	1
CH_4	28
N_2O	265

Note: IPCC 2013 GWP 100a method.

The emissions of non-CO_2, GHG emissions and CO_2 emissions are elaborated on below.

Non-CO_2, GHG emissions
Agriculture accounts for the largest share of non-CO_2 GHGs; around 56% in 2005 (IPCC, 2014). The IPCC identifies the major sources of non-CO_2 GHGs in agriculture as:
- enteric fermentation, a digestive process through which ruminant animals emit methane (CH_4) (32-40% of non- CO_2 GHG emissions in agriculture);
- manure on pasture (15%);
- synthetic fertilizer (12%);
- and paddy rice cultivation (11%).

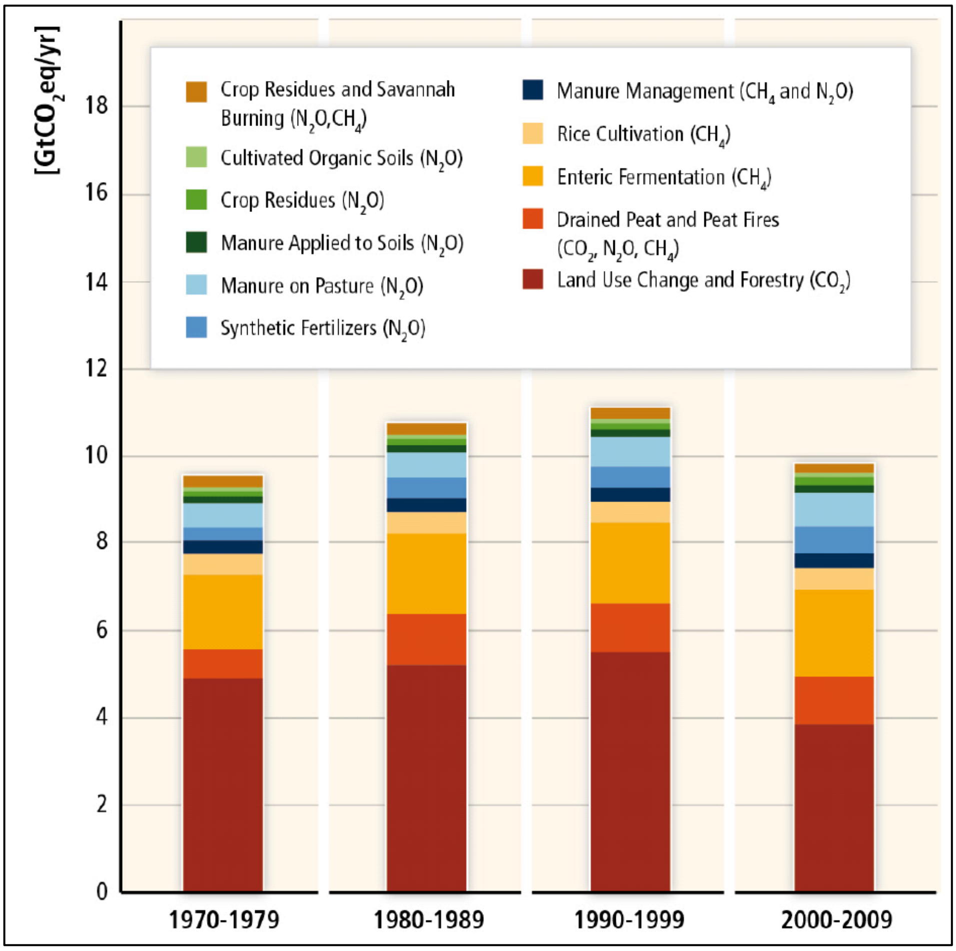
Total Non-CO_2 GHGs from agriculture are estimated to be 5.2-5.8 $GtCO_2$ eq per year (IPCC, 2014). This accounts for around 10-12% of the total global GHGs. These figures do not include emissions related to Land Use Change (LUC).

Biogenic CO_2 emissions
CO_2 is taken up by plants during growth. At the end of the life cycle of food products, this CO_2 is emitted again. These are biogenic emissions; the source is organic. Compared with fossil carbon, this cycle of uptake and emission is short. In this study we only look at the GHG emissions related to the agriculture phase (and upstream processes such as fertilizer production). Because we know that (biogenic) CO_2 is emitted at the end of the life cycle, the uptake of CO_2 in the production phase is not included.

Land-use change CO_2 emissions
When land is deforested to convert forest to agricultural area, emission of CO_2 takes place. These emissions are additional to the natural carbon cycle; they are not necessarily taken up again within a short time span. The IPCC reports a considerable emission due to deforestation, but also a considerable sink due to reforestation/regrowth. When calculating land-use change emissions, we look back at the past 20 years. This ensures the carbon footprint of the parties benefitting from deforestation in the 20 years after deforestation is negatively affected.

Forestry and other land use (FOLU) accounted for around 12% of CO_2 emissions between 2000 and 2009 (IPCC, 2014) (p.16).
Emissions from agriculture, forestry and land use change in the past four decades are shown in Figure 8 (IPCC, 2014). Emissions related to land use change are decreasing, but still contribute significantly to the global total.

Figure 8 Global GHG emissions from agriculture, forestry and land use in the past four decades



Source: (IPCC, 2014).

3.2 Effects of climate change on agriculture: method

Oxfam is interested in information regarding the effects of climate change on production of crops, in different regions. CE Delft did an exploratory study to find information that has been published on this subject. The results of this 2-day literature and web-scan are elaborated on in the following paragraphs.

The effects of climate change on agriculture and food security are included in reports by renowned international organisations such as the Food and Agriculture Organization of the United Nations (FAO), The Intergovernmental Panel on Climate Change (IPCC) and the International Food Policy Research Institute (IFPRI). For further information we refer to reports such as:

- IPCC, 2014, 5th Assessment Report:
    - Chapter 11 'Agriculture, Forestry and Other Land Use (AFOLU)';
    - Chapter 7 'Food Security and Food Production Systems'.
- FAO, 2003, World Agriculture towards 2015/2030 and World Agriculture towards 2030/2050;
- IFPRI, 2010, Food Security, Farming, and Climate Change to 2050.

These reports refer to numerous other peer-reviewed articles.

3.3 Effects of climate change on agriculture: types of impact

Climate change will affect food production in numerous ways.
The FAO distinguishes three groups of impacts (FAO, 2003):

1. Direct impacts (e.g. higher temperatures).
2. Indirect impacts (e.g. loss of biodiversity).
3. Impacts related to enhanced climate variation (e.g. more intense extreme events).

These are summarized in Figure 9. Not all of the impacts of climate change on agriculture are disadvantageous. The most important impacts are elaborated on below.

Effects on crops

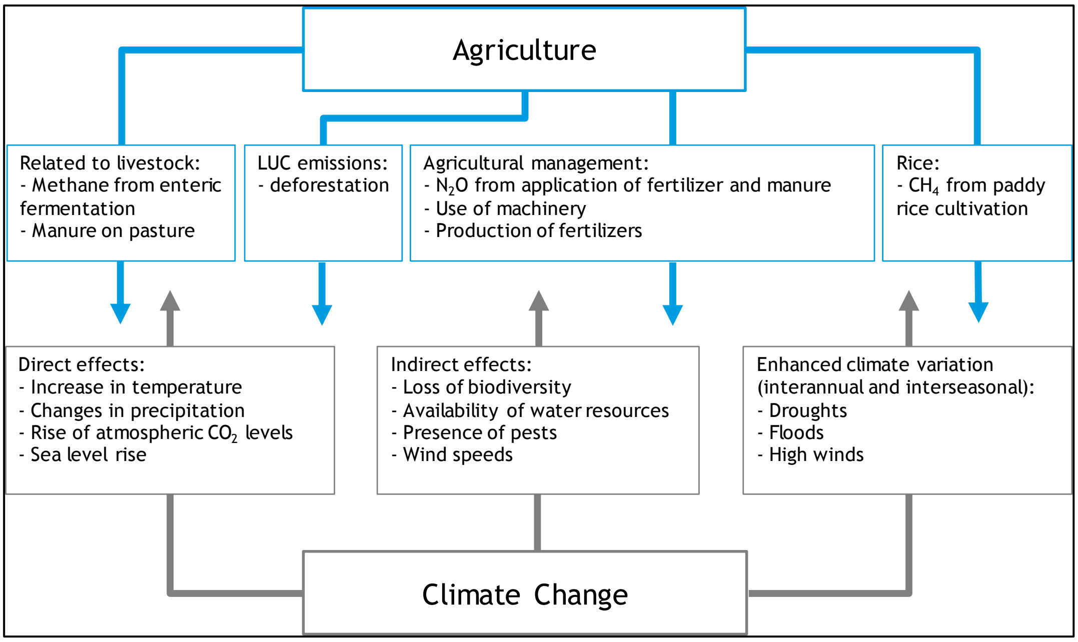
Direct effects are related to changes in temperature, atmospheric CO_2 levels and precipitation, summarized in Table 5. Some of these changes can affect crops growth both positively and negatively.

Higher atmospheric CO_2 levels give rise to the 'CO_2 fertilizer effect', which stimulates photosynthesis (FAO, 2003). It also increases water efficiency (FAO, 2003). Higher temperatures can increase crop growth and can also increase the area suitable for agriculture, especially in temperate regions. In semi-arid, arid and (sub)tropical regions, higher temperatures means the temperatures may rise above the crop tolerance level. This results in reduced yields. Furthermore, it can increase heat stress in livestock (FAO, 2003). Precipitation may decrease in areas which already have food security issues, such as Southern Africa. Sea level rise affects agriculture in two ways: loss of agricultural land, and intrusion of saltwater (into land and aquifers used for irrigation).

Table 5 Positive (+) and negative (-) impacts of climate change on agriculture

Climate change impact	Effect
Higher CO_2 levels	CO_2 fertilizer effect: stimulates photosynthesis and water efficiency
Higher temperature	+ Stimulates crop growth + Increases the area suitable for agriculture (especially in temperate regions) - Reduced yields - crops have a tolerance level - Increase of heat stress in livestock
Decrease in precipitation	- Decreased yields because of lower water availability
Sea level rise	- Loss of agricultural land - Intrusion of saltwater

Figure 9 **Relationship between agriculture and climate change (based on (FAO, 2003)**



Source: IPCC, 2014, Chapter 11.

Indirect effects and enhanced climate variation impact agriculture and food security indirectly. Loss of biodiversity may leave crops more vulnerable to pests, while warmer winters may increase the presence of pests.
Water resources are predicted to be less available: runoff and groundwater recharge are expected to decrease (FAO, 2003). Higher wind speeds will increase erosion. These indirect effects from climate change do directly affect agriculture.

Finally, the incidence of intense extreme events is expected to increase. Though these events are usually local in nature, and often do not affect global food production significantly, local effects on food security are substantial. Such events rob people from their to-be-harvested crops, stored food, machinery and tools, homes, communities and savings, and therefore threaten (local and regional) food security.

Specific regions vulnerable to the impacts described above are summarized in the bullet point list in Figure 10.

Figure 10 Food-insecure regions and countries at risk

Climate change

- Countries of arid, semi-arid and subtropical Asia, sub-Saharan Africa, Near East/North Africa and Latin America where temperatures are above the optimum for crop growth or even close to their maximum temperature tolerance, and already result in heat stress in livestock and fish.
- Water-scarce countries of arid, semi-arid and subtropical Asia, sub-Saharan Africa, Near East/North Africa and Latin America (northeast Brazil) where reduced stream flow and water recharge, higher transmission losses from irrigation systems and greater evapotranspiration from crops may lower irrigation and increase water stress in crops and livestock.

Sea level rise

- West Africa (Gulf of Guinea, Senegal and the Gambia), southern Mediterranean (Egypt), East Africa (Mozambique), South and Southeast Asia (Bay of Bengal), the Caribbean and island states of the Indian and Pacific Oceans.

Extreme events

- Droughts for much of semi-arid and subhumid Africa (particularly the Sahel, Horn of Africa and southern Africa), South Asia and northeast Brazil.
- Floods in deltas and their immediate hinterland during storm surges.
- Floods in river valleys and lake basins of all regions, including temperate ones, during abnormally long or intense rainfall events.
- High winds associated with tropical cyclones in Central America and the Caribbean, South and East Asia.

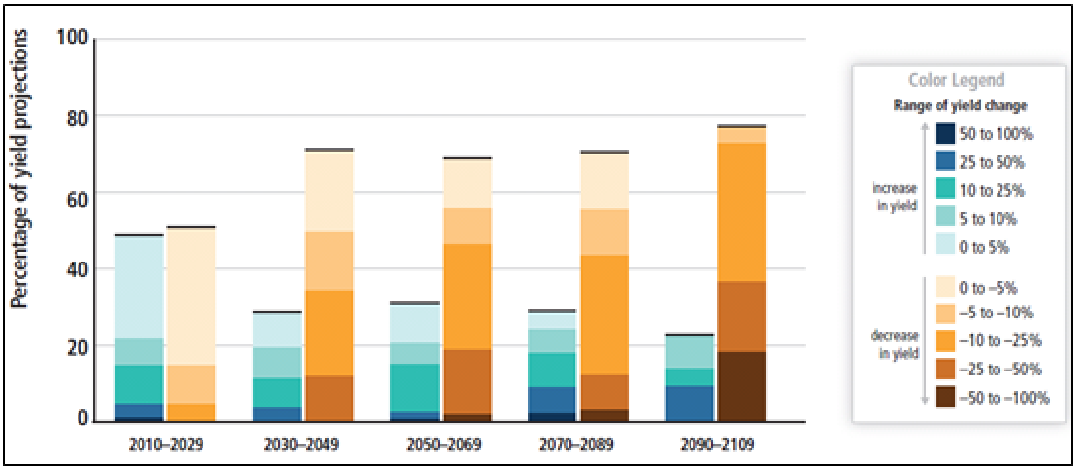
Source: FAO, 2003.

Yield projections

Numerous yield projections have been made, most of which focus on cereals (staple food, large proportion of global average diet). Figure 11 summarizes the projected changes in (regional) crop yields, from a large number of studies.

As can be seen, the number of studies projecting an increase in yields decreases over time. Furthermore, the relative decrease in projected yields increases; projected decreases for the period 2090-2109 are higher than the projected decreases in the period 2010-2029.

Figure 11 Summary of projected changes in crop yields, due to climate change. Includes projections for different emission scenarios, for tropical and temperate regions and for adaptation and no-adaptation cases



Source: IPCC, 2014, Chapter 7.

The IPCC Table 6 summarizes cereal yield projections (potential change in yields) for a number of regions (IPCC, 2014). A factor which makes yields projections more uncertain is how influential the CO_2 fertilizer effect will be. This effect may increase crop growth and water efficiency, but the extent is still uncertain (Parry, et al., 2004). Between brackets (in Table 5) the yield projections including the CO_2 fertilizer effect are shown.

Table 6 Potential changes in cereal yields, by region, from different studies. Summary of Box 7.1 in the IPCC's fifth Assessment Report (IPCC, 2014)

Region	Scenario year, crop, subregion and yield impact (%)	
World	2050, maize 2050, rice 2050, wheat	-2 to-12 (rainfed), -4 to-7 (irrigated) -1 to 0.07 (rainfed), -9.5 to-12 (irrigated) -4 to-10 (rainfed), -10 to-13 (irrigated)
Asia	Eastern Asia, rice, 2030 (+CO_2 effect) Idem, 2050 Idem, 2080	-10 to +3 (+7.5 to +17.5) -26.7 to +2 (0 to +25) -39 to -6 (-10 to +25)
	South Asia, net cereal production (3°C)	-4 to -10
Africa	All regions, 2050, wheat Idem, maize Idem, sorghum Idem, millet	-17 -5 -15 -10
Central and South America	Central America, 2030, wheat Idem, rice Idem, maize Idem, bean	-1 to -9 0 to -10 and +3 0 -4 Yield impacts increase with time, all crops show lower projections for 2050, 2070 and 2100
North America	US, Midwest and Southeast, 0.8°C, soy Idem, maize	-2.4 to +1.7 (+5.0 to +9.1, incl. CO_2 effect) -2.5 (-1.5, incl. CO_2 effect)
Europe	Region with highest increase in yields of wheat, maize and soybean Regions with highest decrease in yield of wheat, maize and soybean	Boreal: +34 to +54 Atlantic South/ Mediterranean South: -26 to-7 and -27 to +5 resp.
Australia	South, 2080, including CO_2 effect Southeast, 2080 (+ CO_2 effect)	-15 to -12 -29 (-25)

In their fifth Assessment Report, the IPCC (IPCC, 2014) concludes that:
- climate change affects crop and (terrestrial) food production. Negative impacts are more common than positive ones;
- in low-latitude countries, crop production will be *'consistently and negatively affected by climate change in the future'*;
- in high latitude countries, climate change may affect crop production positively or negatively (uncertain).

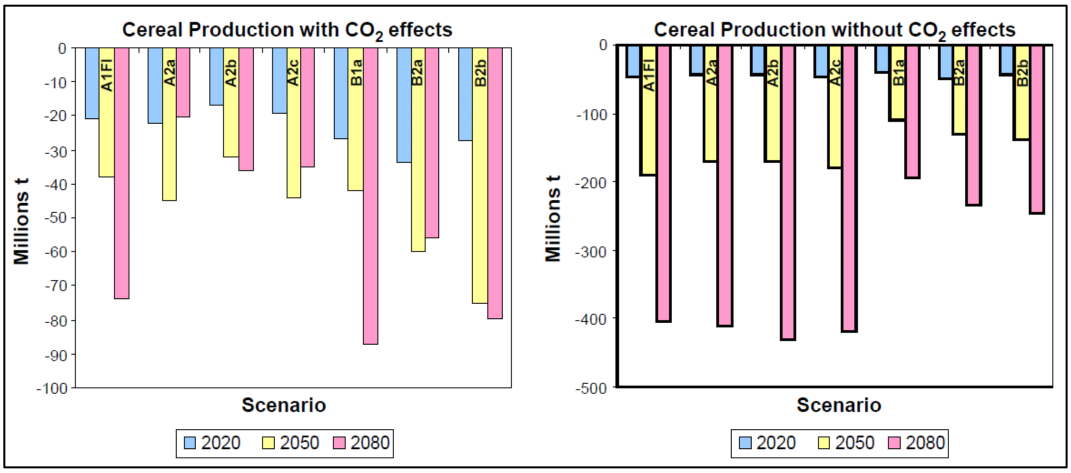
The International Food Policy Research Institute estimates cereals yields (maize, rice and wheat) to decrease in most scenarios in most regions, for 2050 compared to 2000 (IFPRI, 2010). The only crop which they estimate may benefit from climate change may be rice, which shows a 0.07% increase in one of the scenarios (but a decrease of 1.05 in another). They conclude that for all regions climate change will affect productivity negatively, which will result in reduced food availability and reduced human well-being (IFPRI, 2010).

Parry et al. (Parry, et al., 2004) explore the potential changes in yields under different emissions scenarios (based on the IPCC's Special Report on Emission Scenarios), for a total of seven scenarios. Parry et al. conclude that:
– world crops yields are likely to be negatively impacted by climate change;
– differences between regions are likely to become more pronounced; in developed countries cereal yields are more likely to increase, while in developing countries they are more likely to decrease.

Overall, they conclude that we will be able to grow enough food to feed the global population, but that food security and equality will be more of a challenge for poorer regions, as these regions will feel the impacts of climate change more strongly.

Overall, (Parry, et al., 2004) predict global cereal production to decrease in all scenarios, with and without accounting for the CO_2 fertilizer effect (as shown in Figure 12).

Figure 12 Changes in global cereal production due to anthropogenic climate change under seven SRES scenarios with and without CO_2 effects, relative to the reference scenario



Source (Parry, et al., 2004).

Summary
Yield projections are always linked to a scenario with assumptions on e.g. population growth, economic growth and technological innovation. Together with uncertainties concerning the CO_2 fertilizer effect, this creates a wide range of possible outcomes. The results shown above show that climate change will likely affect agriculture negatively on a global scale, although regionally or locally some positive effects may occur. Positive effects (higher yields) are more likely at higher latitudes (correlated to more developed regions; Europe and North America). Effects can be expected on a short term; even for 2020 yields are projected to change (decrease) in many countries. Almost all projections focus on cereals, as this is the main staple food. This does not mean that other commodities will not be affected by climate change.

3.4 Public campaigns on effects of climate change

Most large NGO's have climate change on their agenda's. Their focus is on different aspects related to climate change: causes and mitigation, adaptation and also effects of climate change. These effects of climate change are usually described qualitatively, for instance by the WWF.

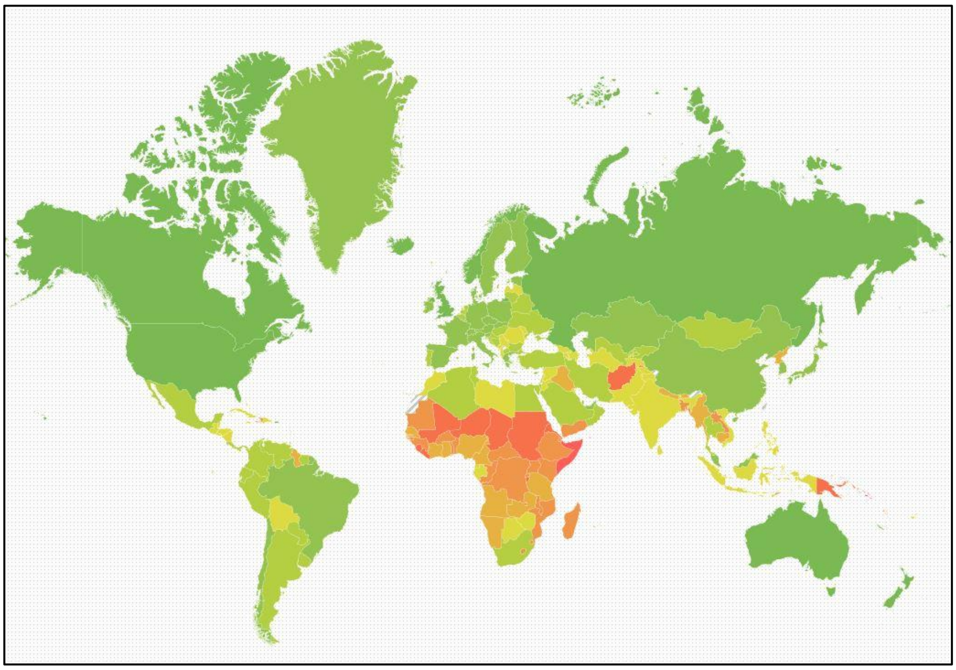
World Wildlife Fund
The WWF describes the effects of climate change on (people in) impacted places impacted regions: the Amazon, the Arctic, Coastal East Africa, the Coral triangle, the Eastern Himalayas (WWF, 2014). Qualitative relationships between climate change and food production are given.

Oxfam wants to map footprints on a global scale, and wants to link this to vulnerability to climate change.

To give Oxfam an idea of what is already out there, we have searched for NGO's and other organizations which map impact of climate change or climate change vulnerability.

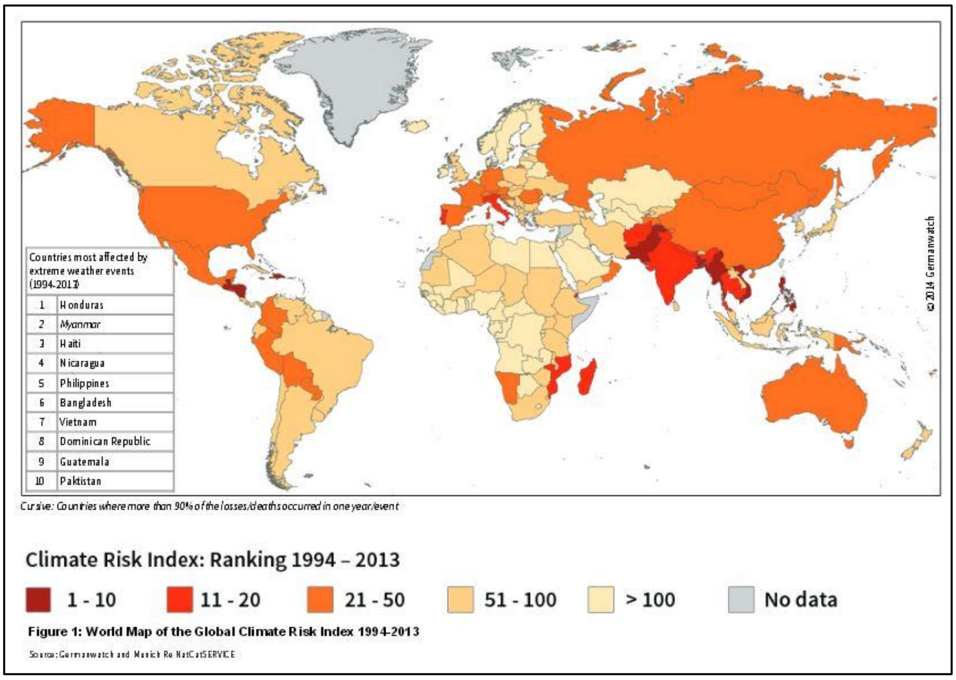
ND-GAIN Index
The ND-GAIN Index is a project of the University of Notre Dame Global Adaptation Index (ND-GAIN, 2014). The index combines a vulnerability (to climate change) score to a readiness (to improve resilience) score. One of the aspects of vulnerability is 'food': '*The Food score captures a country's vulnerability to climate change, in terms of food production, food demand, nutrition and rural population. Indicators include: projected change of cereal yields, projected population growth, food import dependency, rural population, agriculture capacity, and child malnutrition*'. The ND-GAIN vulnerability score is shown in a map in Figure 13.

Figure 13 World map of the ND-GAIN vulnerability score



Germanwatch – The Global Climate Risk Index
Germanwatch annually publishes the Global Climate Risk Index. The 10th edition was published in 2015. Germanwatch summarizes the Global Climate Risk Index as follows: '*The Global Climate Risk Index 2015 analyses to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.). The most recent data available – from 2013 and 1994-2013 – were taken into account*' (Germanwatch, 2015).

Figure 14 World map of the Global Climate Risk Index (Germanwatch, 2015)

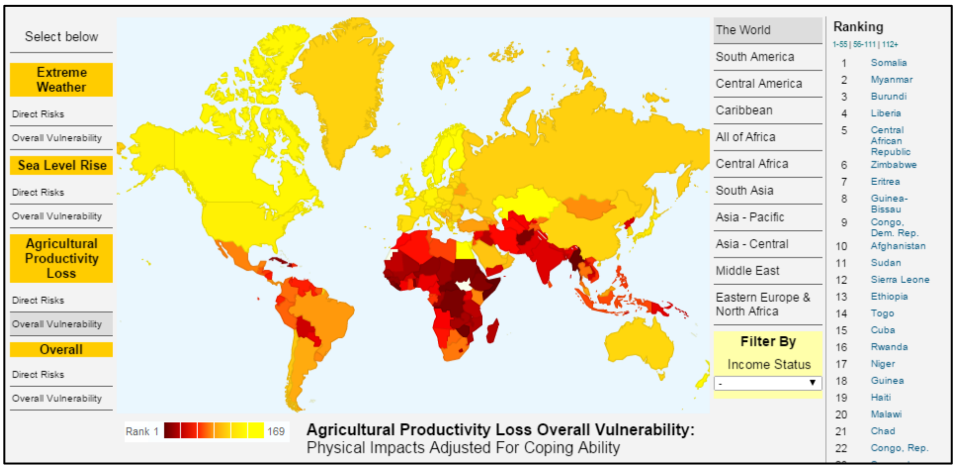


Source: (Germanwatch, 2015).

Center for Global Development

The [Center for Global Development] assessed the vulnerability to climate change of 233 countries (Center for Global Development, 2014).
Three separate aspects can be shown in maps, divided into risk and overall vulnerability for that aspect. These are extreme weather, sea level rise and agricultural productivity loss. The background datasets are available free of charge.

Figure 15 Agricultural productivity loss

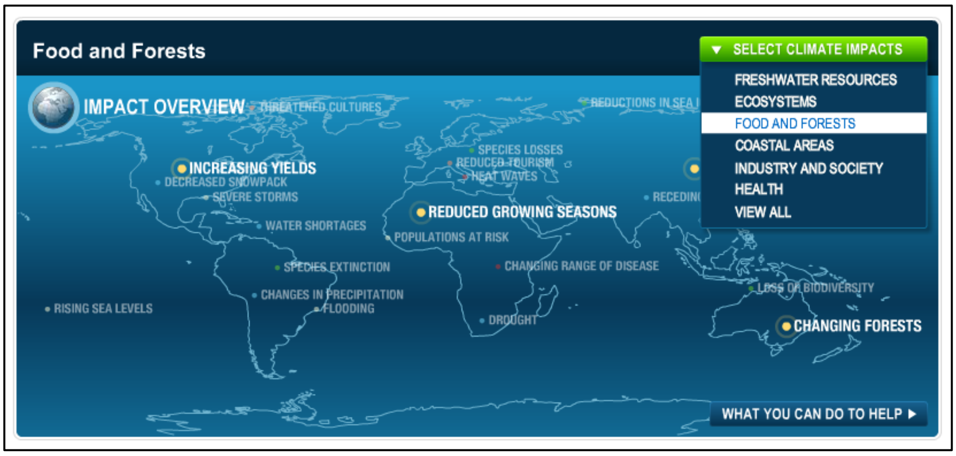


Source: (Center for Global Development, 2014).

National Geographic

The Global Warming Effects Map (National Geographic, n.d.) qualitatively presents the effects of climate change on different parts of the world. Effects are subdivided into different types of impacts, e.g. ‘food and forests’ and ‘freshwater resources’ (see Figure 16). One can click on each of the items to get a little more information (and a beautiful picture).

Figure 16 Global Warming Effects Map



Source: (National Geographic, n.d.).

Union of Concerned Scientists

The Union of Concerned Scientists created the Climate Hot Map (Union of Concerned Scientists, 2011). Several aspects related to different areas of protection (People, Freshwater, Oceans and Ecosystems) can be selected to give insight into the impact of climate change on specific locations. Each of the tags (see Figure 17) is a link to information about that specific location.

Figure 17 Climate Hot Map Union of Concerned Scientists, 2011

Source: (Union of Concerned Scientists, 2011).

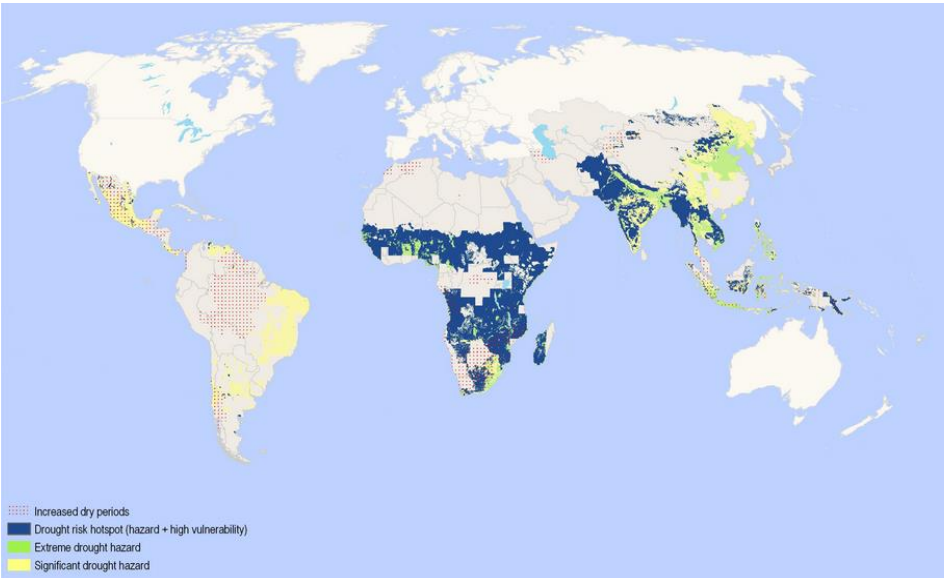
United Nations Framework Convention on Climate Change (UNFCCC)
The UNFCCC shows the projected impacts and vulnerabilities for seven regions (North America, Latin America, Europe, Africa, Asia, Australia and New Zealand and Small Island States) (UNFCCC, 2014). A summary is given on the impacts on a number of aspects important to that region, e.g. food or freshwater. The projected impacts are based on the IPCC's Fourth Assessment Report. For each of the regions, there are links to country profiles.

Figure 18 Projected impacts of climate change

Source: UNFCCC, 2014.

CARE – Climate Change Information Centre
In different maps, CARE shows the humanitarian implications of climate change, for the next 20-30 years (CARE, n.d.). They focus specifically on regions with a high vulnerability. The focus is on specific hazards (extreme weather events): floods, cyclones and droughts. An example is the map in Figure 19 which shows drought risk hotspots in blue.

Figure 19 World drought risk, CARE



Source: (CARE, n.d.).

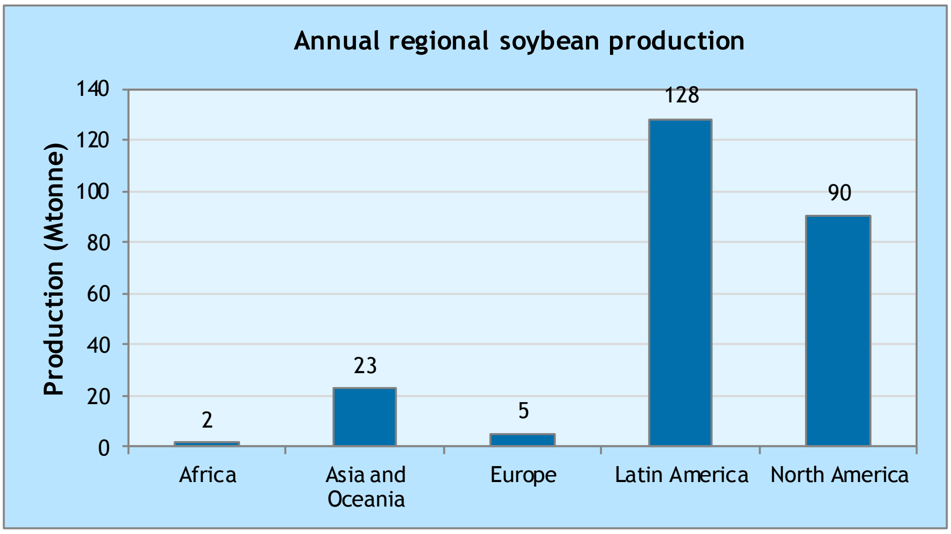
4 Commodity footprints

Based on the method and life cycle inventories described in Chapter 2, we calculated GHG footprints and water scarcity footprints per commodity. In the following paragraphs we present the footprints for the commodity soybean. In the accompanying excel workbook, all commodities are incorporated. We present only soybeans here to give an impression of the results.

4.1 Soybean: Production

As shown in Figure 20, half of all soybeans (50%) is produced in Latin America. North America takes second place, accounting for 35% of the annual global production.

Figure 20 Annual regional soybean production



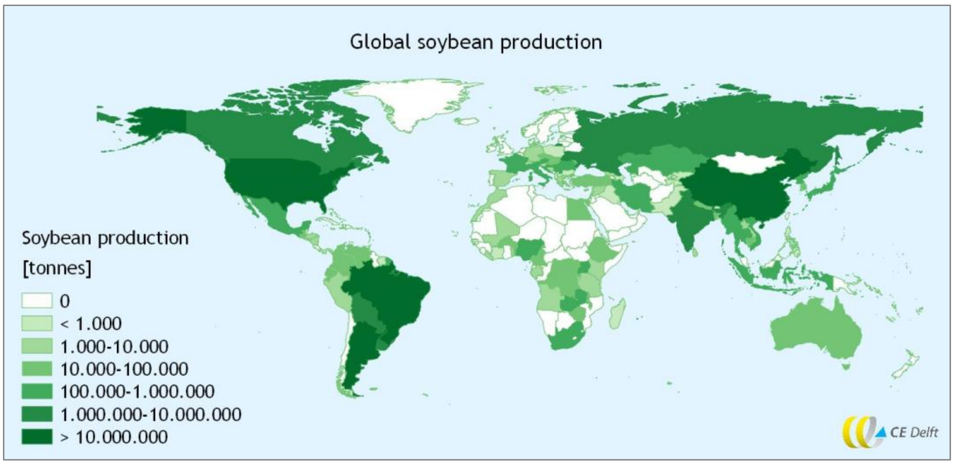
In Table 7 regional production and total global production of soybeans is presented, as well as average yields in the five regions. For elaboration on the calculation of the average yield we refer to Annex B.

Table 7 Total regional production, area under harvest and average regional yield for soybean, based on (FAO, 2014), averages of data for 2010-2012

	Production (Mtonnes)	Fraction of total production (%)	Average yield (tonnes/hectare)
Africa	1,6	1%	1.1
Asia & Oceania	30,3	12%	1.5
Europe	5,4	2%	1.7
North America	90,2	35%	2.8
Latin America	128,3	50%	2.8
Total	**248,2**	**100%**	

Figure 21 shows the production quantities per country. Top producers are Argentina, Brazil, China and the United States.

Figure 21 Global soybean production (average of 2010-2012)

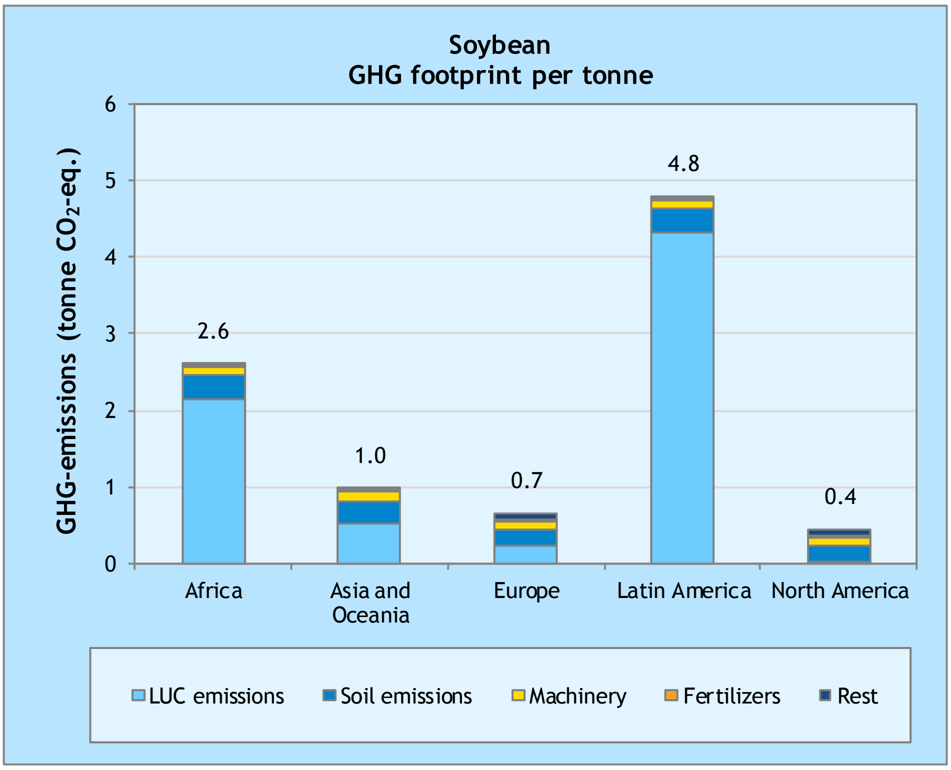


Source of data: (FAO, 2014).

4.2 Soybean: GHG footprint

In Figure 22 regional emissions per tonne of soybean are shown for the different drivers (LUC emissions, soil emissions, machinery, fertilizers and rest).

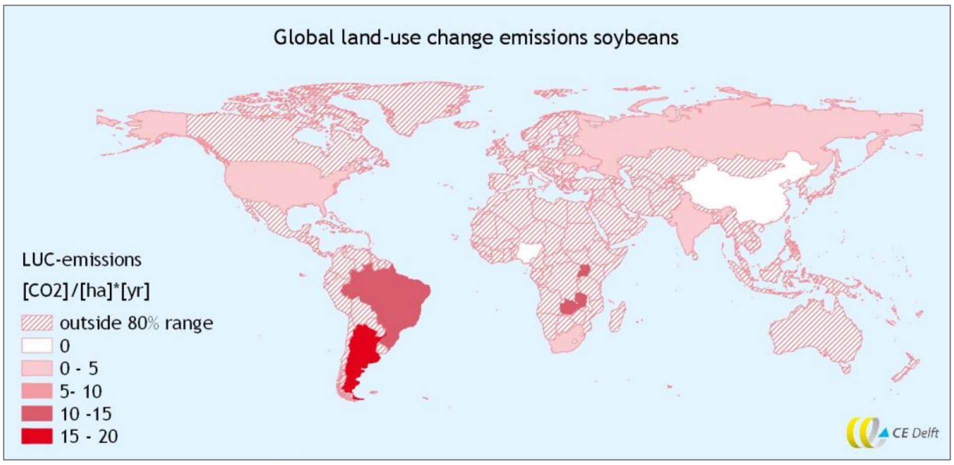
Figure 22 Regional GHG emissions per driver per tonne for soybean



Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

As can be seen in Figure 22 the main difference between the regions are the LUC emissions (land use change emissions, see Section 2.4.3). In Figure 23 the LUC emissions are shown for the countries covering 80% of the regional production (for method see Section 2.2).

Figure 23 LUC emissions in the countries covering 80% of the regional soybean production

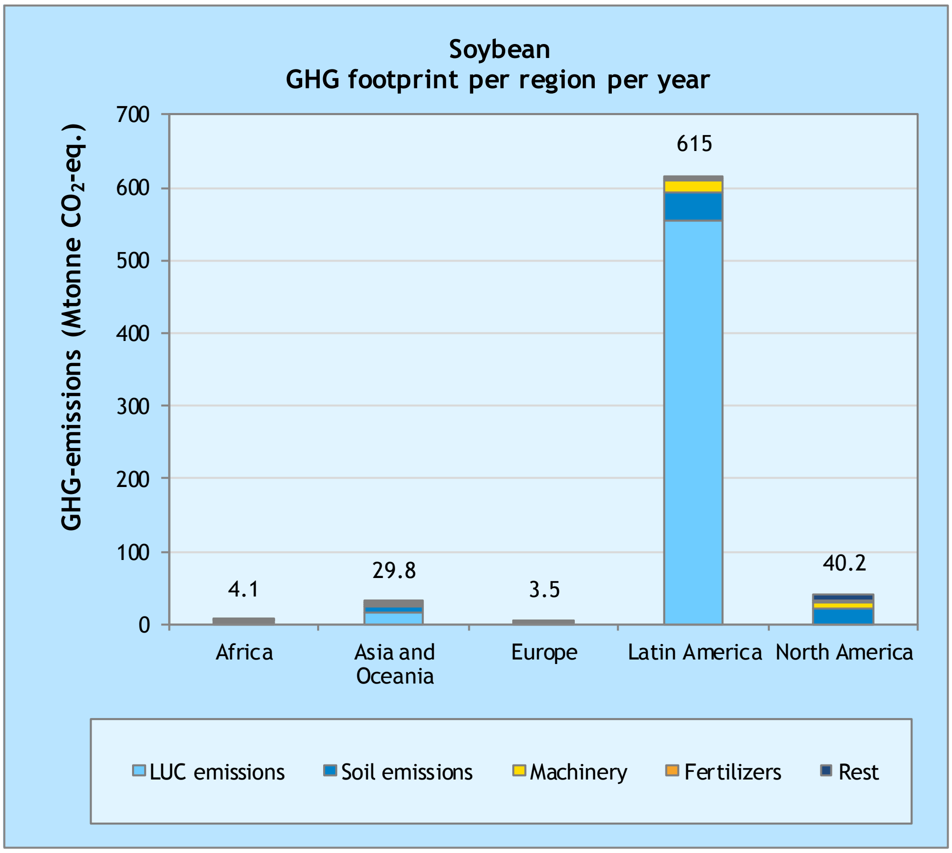


Source of data: (Blonk Consultants, 2013)

While LUC emissions related to soybean are highest in Latin America, yields are also relatively high (see Table 7). Trade-offs and indirect effects need to be taken into account when presenting a shift from one country to another as a good solution. Shifting soybean production from Latin America to Europe could for example mean that production of another crop (with a less favourable yield) shifts from Europe to Latin America. This is called indirect land use change (ILUC).
From a company perspective one only looks at LUC when assessing the impact of food crops. A government view also taken such indirect and systemic effects into account.

Emissions per tonne are highest in Latin America, and so is production. Therefore, it is no surprise that the regional GHG footprint is by far highest in Latin America. LUC plays an important role in this total; 90% of the GHG footprint for soybeans in Latin America is accounted for by LUC. This can be explained by the relatively high increase in demand. Production and harvested area have both increased over 3 times in the past 20 years, respectively 3.5 and 3.1 times (FAO, 2014).

Figure 24 Annual total regional GHG emissions per driver for soybean

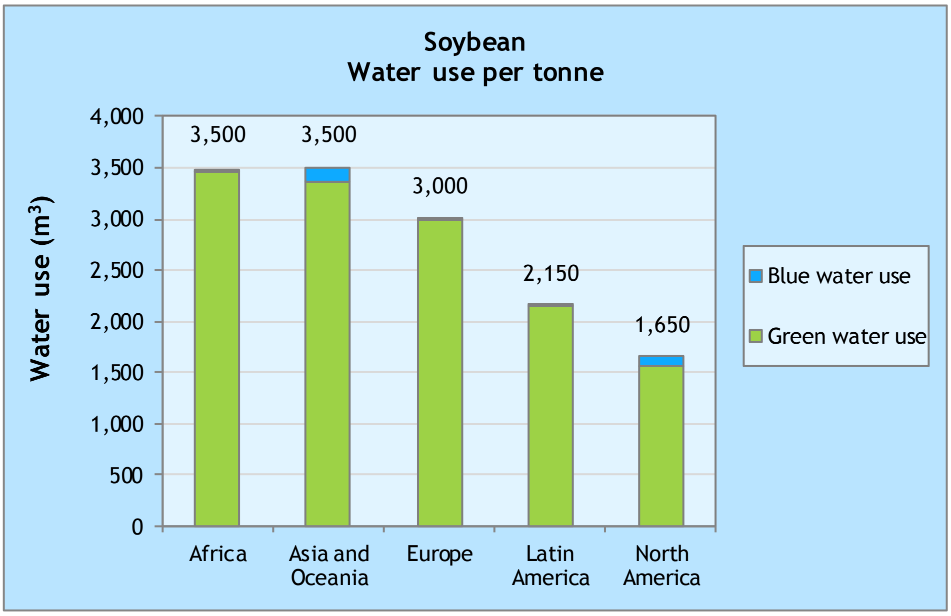


Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

4.3 Soybean: water use

Figure 25 and Figure 26 present green and blue water use per tonne of soybean production and per year for the total regional production. As can be seen, there are big differences, both in green water use and in blue water use (see also Table 8).

Figure 25 Regional green and blue water use for soybean (m^3/tonne)

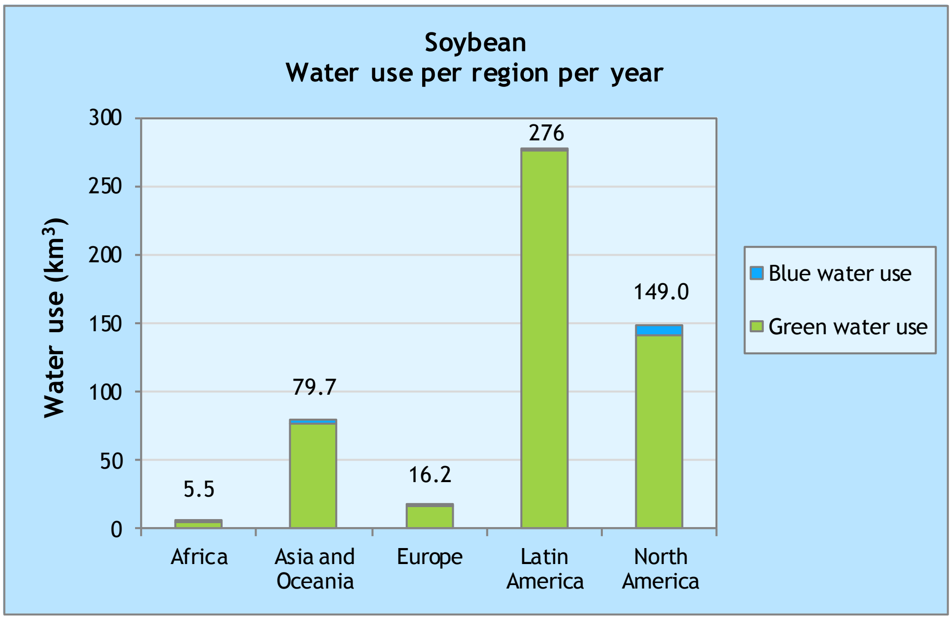


Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

Table 8 Regional blue water use for soybean

	Africa	Asia & Oceania	Europe	Latin America	North America
m^3/tonne	27	140	14	3	92

Figure 26 Annual total regional green and blue water use for soybean production



Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

4.4 Soybean: water scarcity footprint

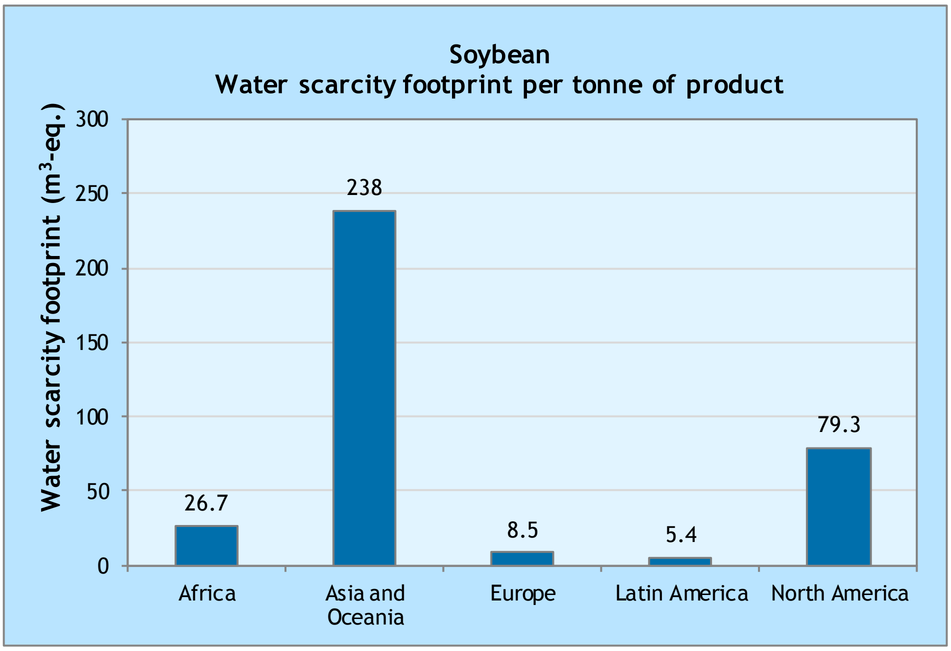
Blue water use is used to calculate the water scarcity footprints. The water scarcity footprints are presented in Figure 27 and Figure 28. These figures respectively show the water scarcity footprint per tonne of production and the annual regional water scarcity footprint for the total regional production of soybean.

We use the unit m^3 eq to clearly distinguish the water scarcity footprint from water use. Water use (m^3) cannot easily be compared because of differences in regional characteristics (e.g. crops water needs, rainfall). In the water scarcity footprint (m^3 eq), these regional characteristics are included.

The water scarcity footprint reflects the use of water in irrigation and the scarcity of such water in a region. For example: in Asia & Oceania almost ten times as much water is used in irrigation as in Europe (Table 8). Furthermore, the water scarcity indicator is almost three times as high. This accounts for the differences shown in Figure 27 and Figure 28.

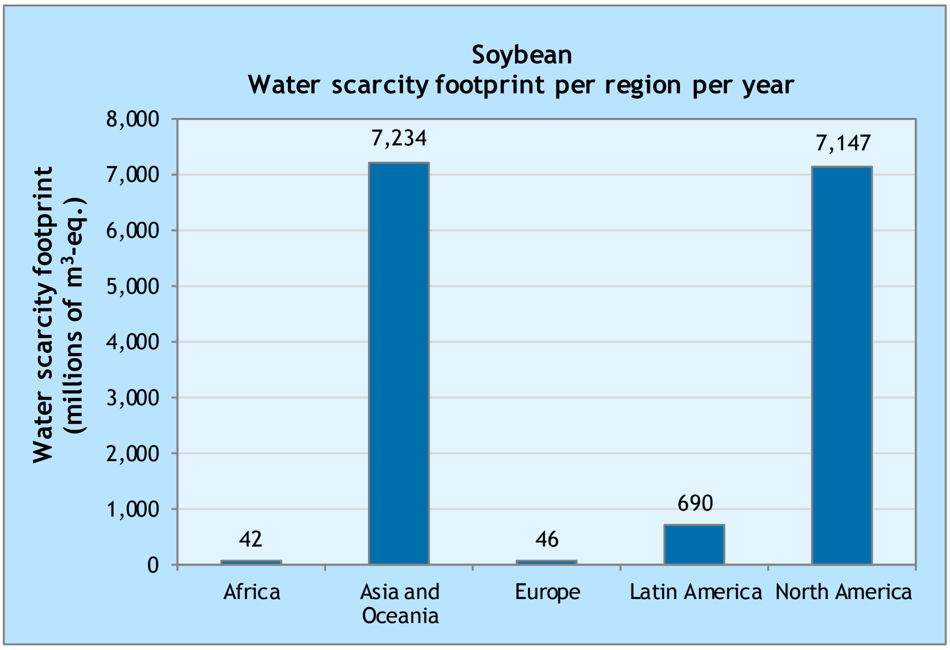
Water use for processes other than irrigation is also included in these figures. This usually contributes little to the water scarcity footprint.

Figure 27 Regional water scarcity footprint per tonne for soybean



Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

Figure 28 Total annual regional water scarcity footprint for soybean

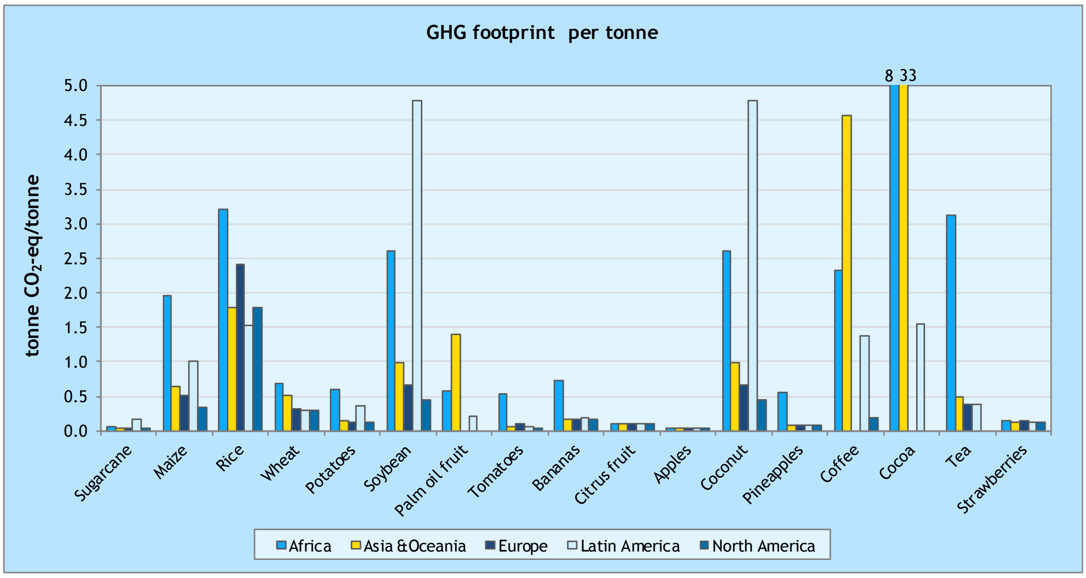


Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

4.5 Comparison of commodities: GHG footprint per tonne

GHG footprints can vary substantially between regions, as we saw for soybean in Figure 22. GHG footprints also vary significantly between commodities, as shown in Figure 29.

Figure 29 GHG footprint per tonne for all seventeen commodities. Commodities are show in order of production quantities (from high to low).

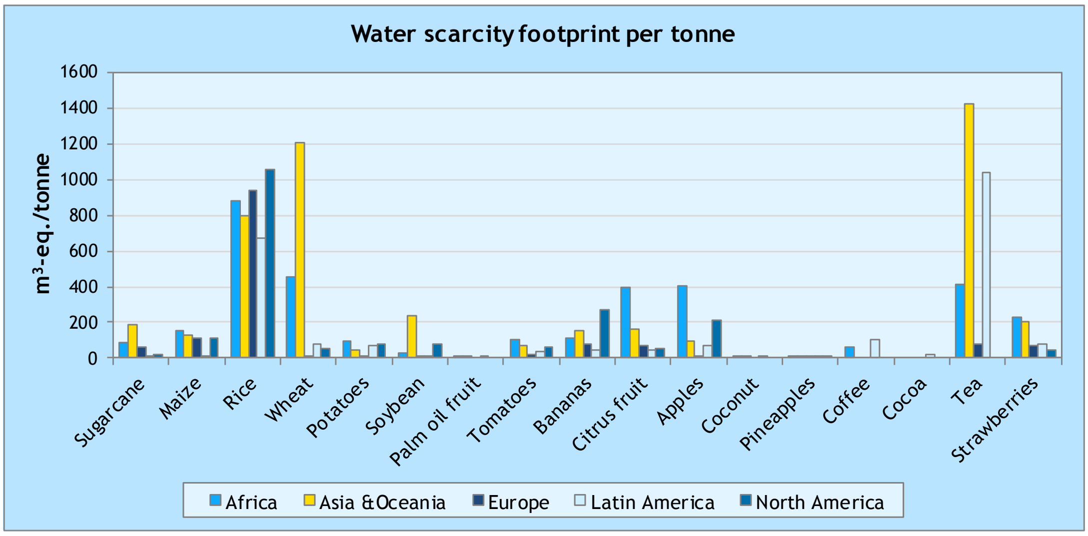


Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

4.6 Comparison of commodities: water scarcity footprint per tonne

Water scarcity footprints can vary substantially between regions, as we saw for soybean in Figure 27. Water scarcity footprints also vary significantly between commodities, as shown in Figure 30.

Figure 30 Water scarcity footprints per tonne for all seventeen commodities. Commodities are show in order of production quantities (from high to low).



Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

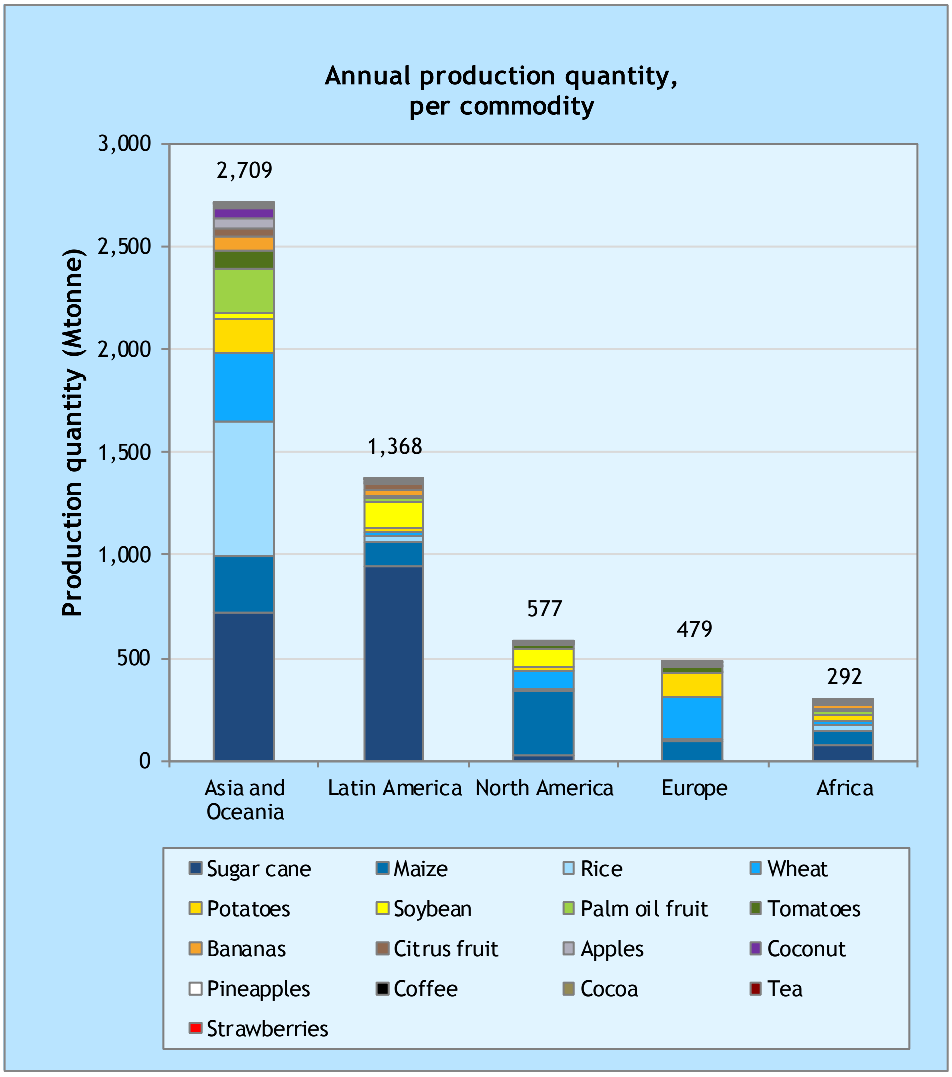
5 Regional footprints

In this chapter we present the regional GHG footprint and water scarcity footprints. The contribution of the different commodities will be shown for both footprints. For the GHG footprint, the contribution of the different drivers (e.g. LUC emissions and machinery) is shown.
Results include the seventeen commodities: palm oil fruit, wheat, rice, maize, soybean, tea, coffee, potatoes, tomatoes, cocoa, coconut, coffee, banana, citrus fruit, pineapple, strawberry and apple.

5.1 Production

Figure 31 shows the annual production quantities for our seventeen commodities. Asia & Oceania has by far the highest production, in volume: 50% of the aggregated total. This region also has the highest population: 4.2 billion or 60% of total global population in 2012.

Figure 31 **Annual production quantities, per region per commodity (Mtonnes)**

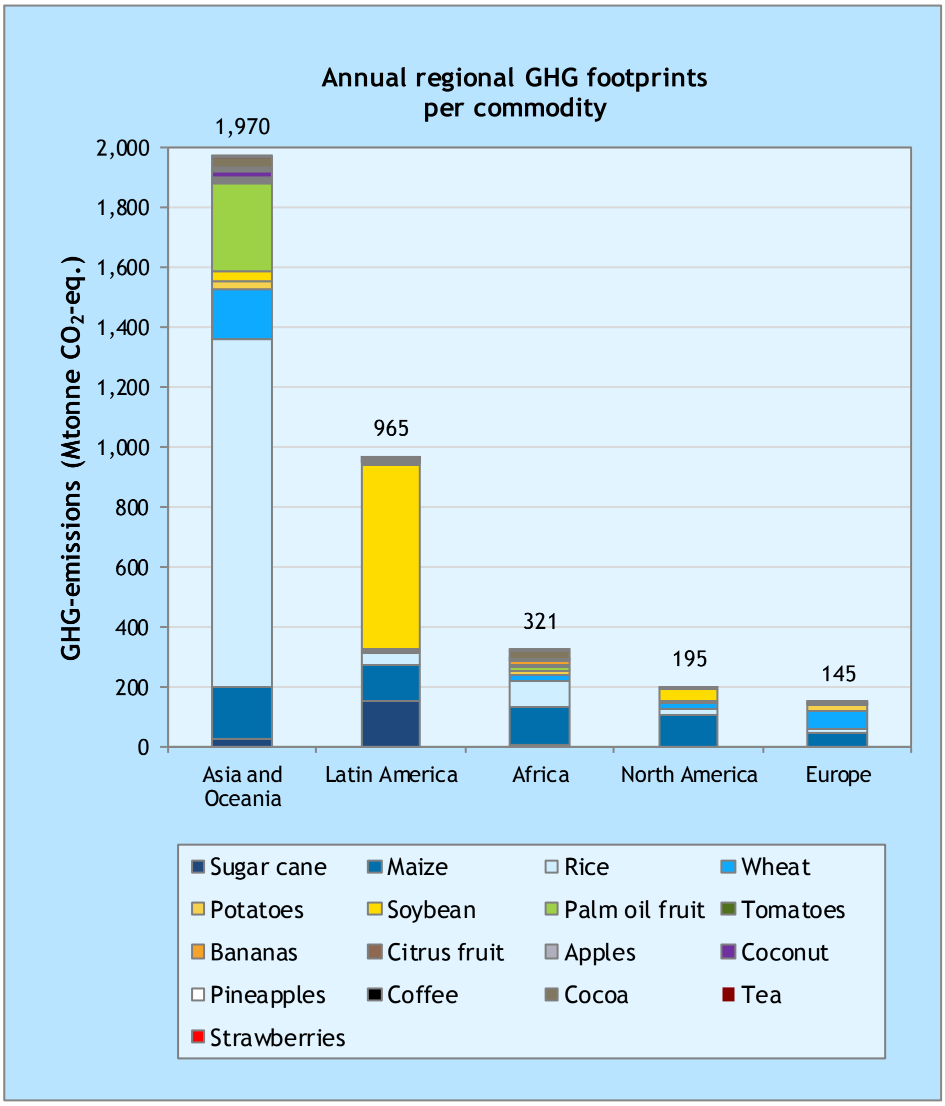


Some regions are larger than others (see Figure 5 in Section 2). Europe includes Russia, Asia & Oceania includes Australia. Australia only comes up once in the list of countries contributing to over 80% of a regional production quantity (for wheat) - 8% of wheat production in Asia & Oceania is produced in Australia. For detailed data on the country contributions to production in a certain region, we refer to the accompanying excel workbook.

5.2 GHG footprint per commodity

In Figure 32 the regional GHG footprints of all seventeen commodities are shown. Based on these commodities, the GHG footprint of Asia & Oceania is by far the highest, and rice contributes most. On a global level, rice contributes 37% of the total GHG footprint of these seventeen commodities.

Figure 32 Annual regional GHG footprints, commodity contribution

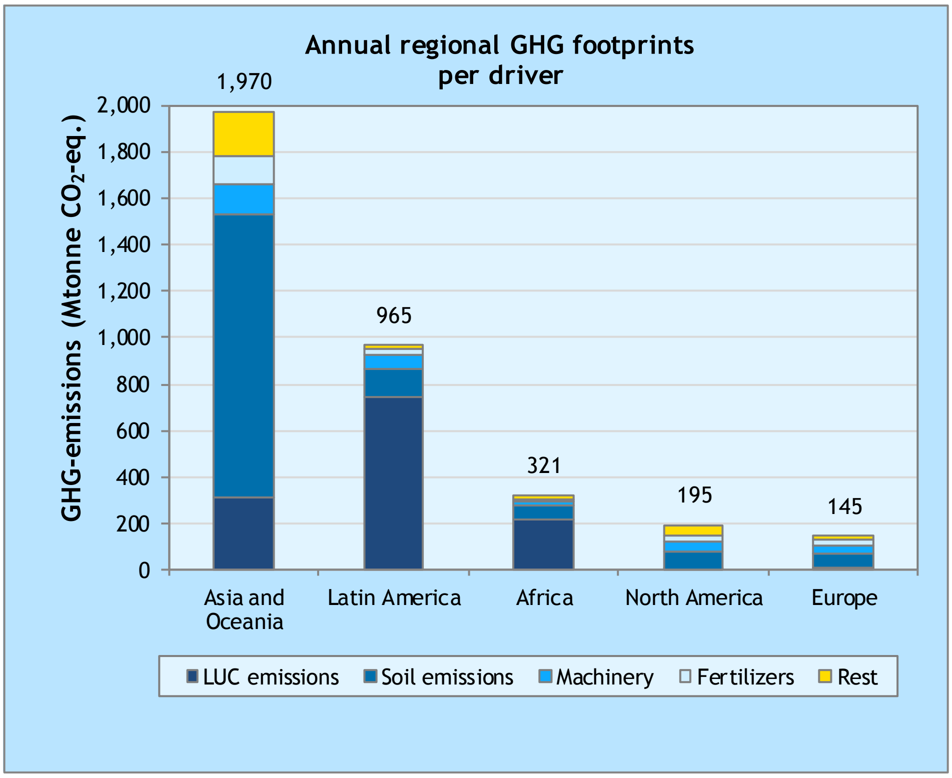


Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

5.3 GHG footprint per driver

Figure 33 shows the contribution of the different drivers to the annual regional GHG footprints, for all seventeen commodities. Soil emissions account for the main share of the high GHG footprint in Asia & Oceania. LUC emissions account for the main share of the high GHG footprint in Latin America.
Soybean from Latin America accounts for 43% of total global LUC emissions.
Rice from Asia & Oceania accounts for 57% of total global soil emissions.

Figure 33 **Annual regional GHG footprints, per driver**



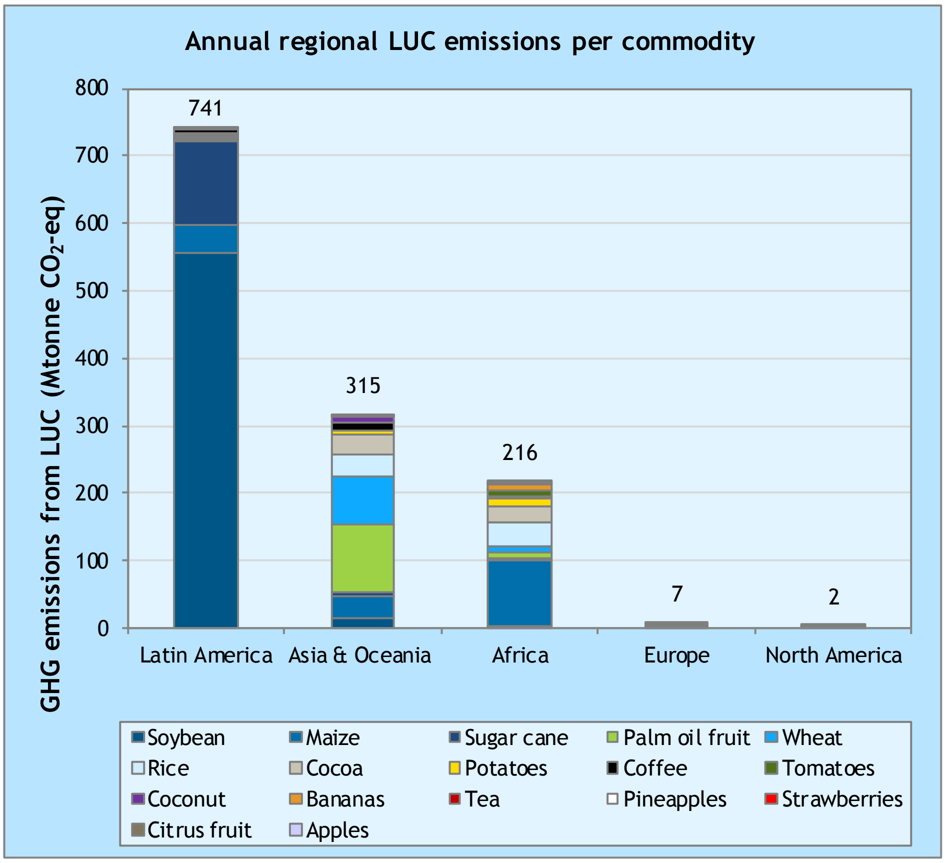
Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

In Figure 34 we show a breakdown of the LUC emissions per region; the LUC emissions per commodity. LUC emissions are highest in Latin America, and are mainly due to production of soybean and sugar cane. In Asia & Oceania and Africa the share of different commodities in the total is smaller; more commodities contribute a significant share.

Table 9 **Contribution of the top 2 contributing commodities to the regional LUC emissions of Latin America, Asia & Oceania and Africa.**

	Latin America	Asia & Oceania	Africa
1.	Soybean: 75%	Palm oil fruit: 32%	Maize: 46%
2.	Sugar cane: 17%	Wheat: 22%	Rice: 17%

Figure 34 Annual regional LUC emissions per commodity

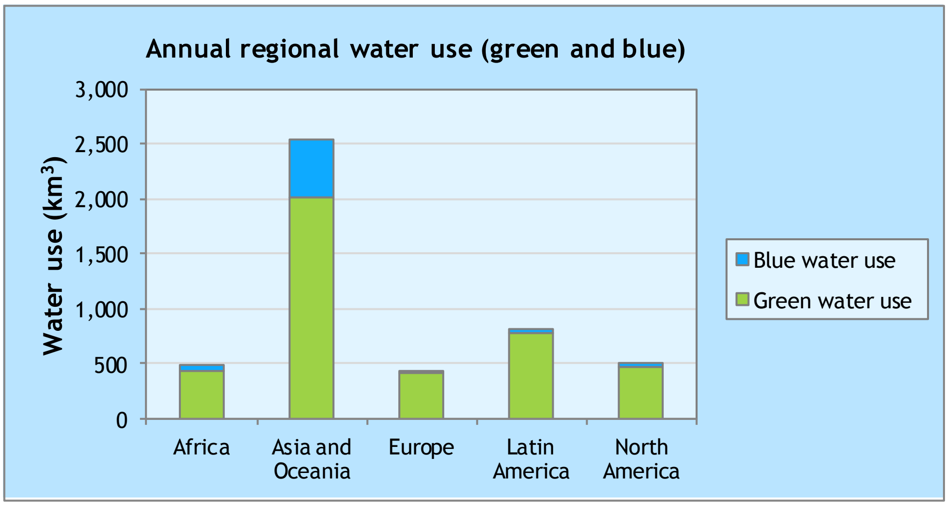


Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

5.4 Water use

Both green and blue water use are highest in Asia & Oceania, as shown in Figure 35.

Figure 35 Annual regional water use (green and blue)



Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle.

Table 10 list the regional annual blue water use (irrigation water) and the regional water scarcity indicators. These data were used to quantify the regional water scarcity footprints.

Table 10 **Annual regional water use and regional water scarcity indicators**

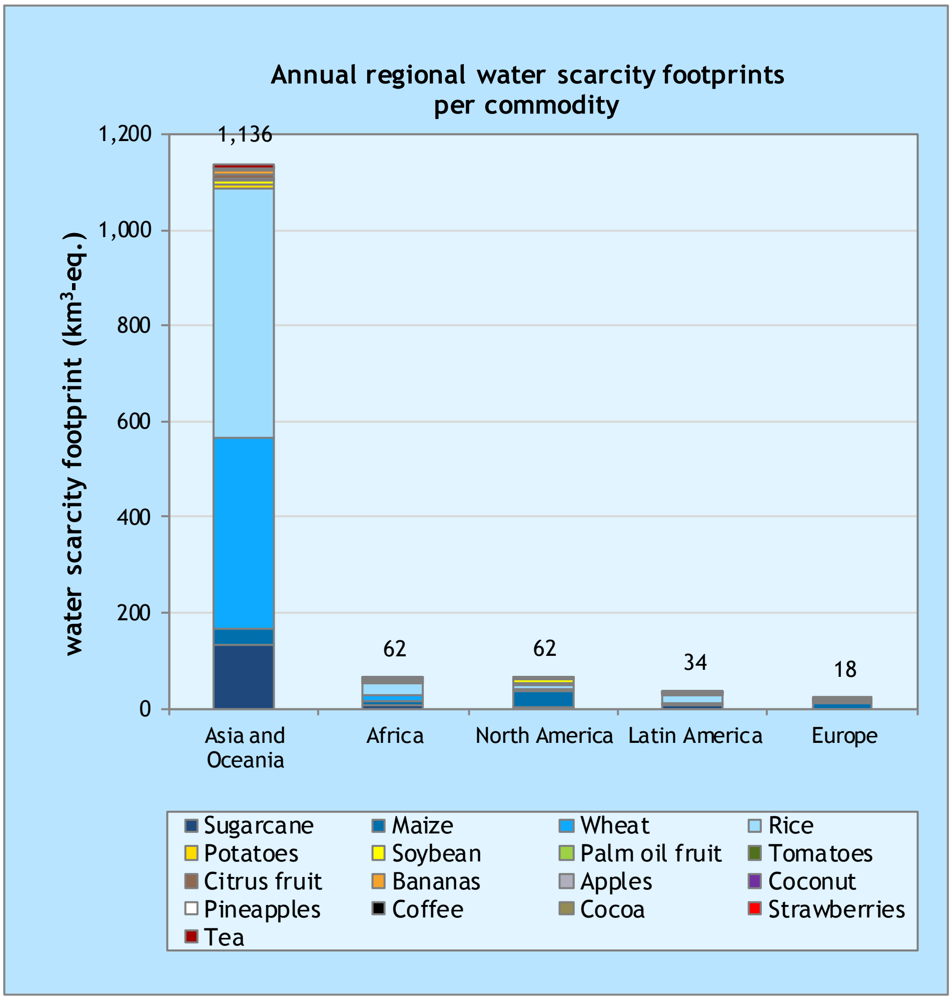
	Africa	Asia & Oceania	Europe	Latin America	North America
Blue water use (km^3)	54	541	22	29	47
Water scarcity indicator (m^3/m^3)	0.98	1.70	0.59	0.85	0.86

5.5 Water scarcity footprint

The water scarcity footprint is highest in Asia & Oceania for two reasons:

1. Blue water use is high, on average around 10 times higher than in the other regions.
2. The regional water scarcity indicator is high; water scarcity is relatively high in Asia & Oceania (see Table 10).

Figure 36 **Annual regional water scarcity footprints, commodity contribution**



Note: The data presented concern the agricultural phase (including preceding phases) of the life cycle. Water use for processes other than irrigation is also included in these figures. This usually (for most commodities) contributes little to the water scarcity footprint.

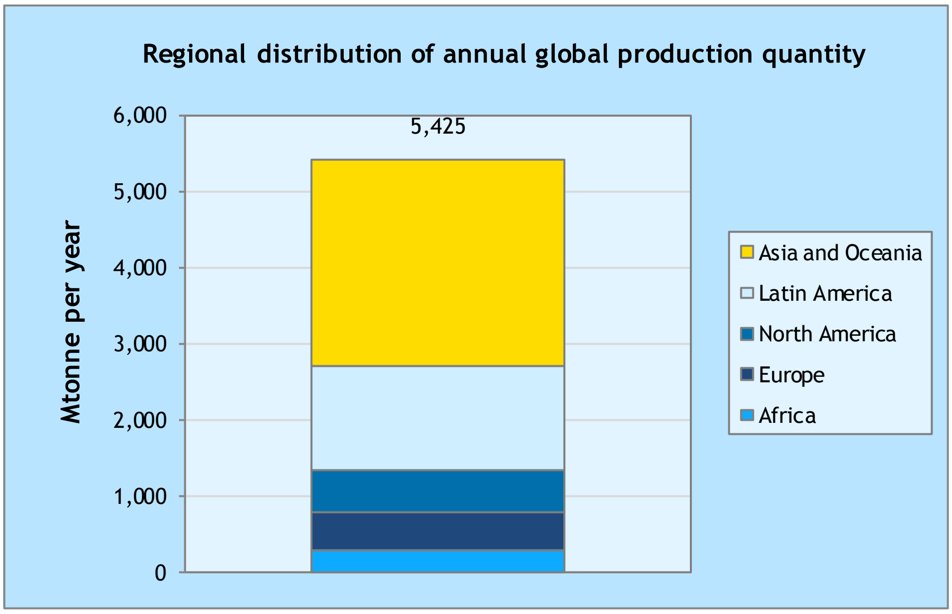
6 Global footprints

In this chapter we present the global GHG footprint and water scarcity footprints. The contribution of the different regions is shown for both footprints. For the GHG footprint, also the contribution of the different drivers (e.g. LUC emissions and machinery) is shown.

6.1 Production

In Figure 31 we showed the commodity contribution to the annual regional production. Figure 37 shows the total global production, and the regional contributions.

Figure 37 Regional distribution of annual global production of the seventeen commodities

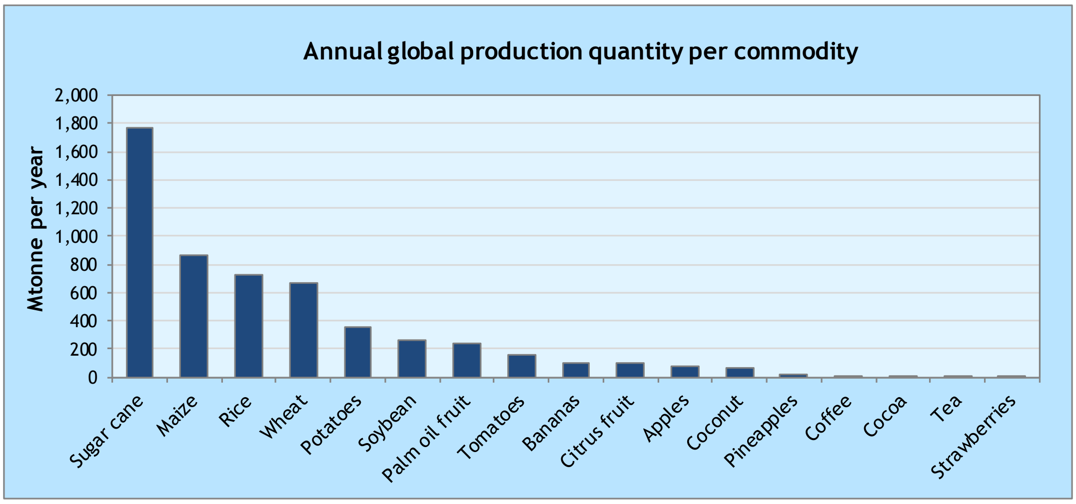


Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

Asia & Oceania accounts for 43% of total global production. This is also the region with the highest population (see Table 12).

In Figure 38 total annual global production is given per commodity. Sugar cane is by far the commodity with the highest production. Sugar cane yields (tonne/hectare) are relatively high, but to yield sugar, the sugar cane needs to be processed. Processing efficiency is around 12% (on a mass basis, 12% of the sugar cane is converted into sugar). By-products can be used as animal feed.

Figure 38 Annual global production quantity per commodity

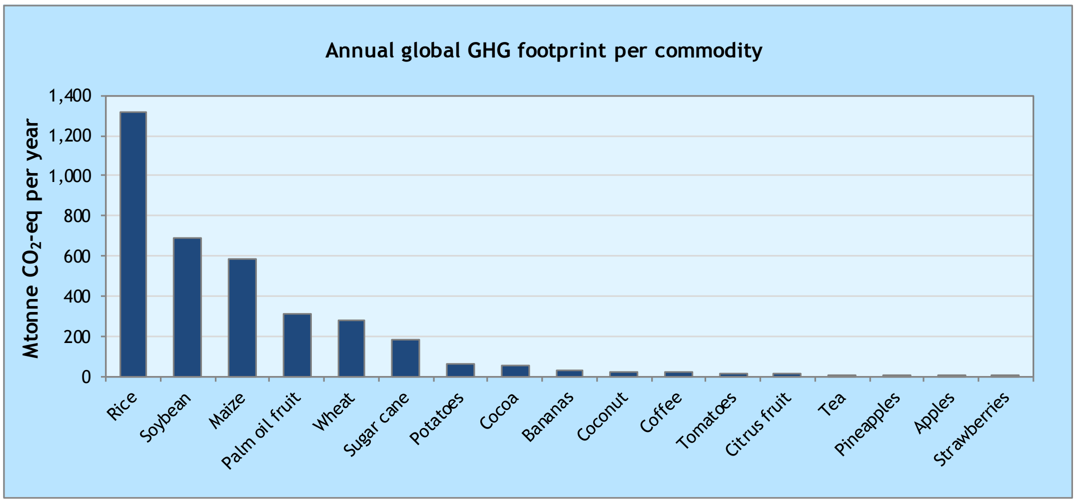


Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

6.2 Global GHG footprint

In Figure 39 the global GHG footprints are presented for all seventeen commodities. Rice accounts for 37% of our global GHG footprint, soybean for 20%, maize for 16%. The main regions for production of these commodities are Asia & Oceania (90% of global rice production), Latin America (50% of global soybean production), and North America (36% of global maize production) respectively.

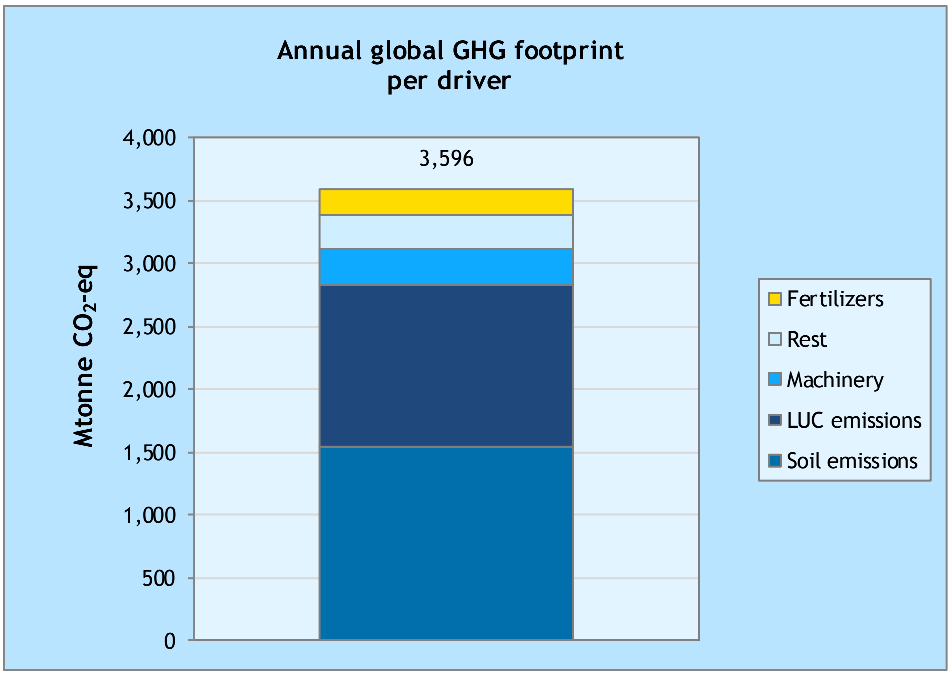
Figure 39 Annual global GHG footprint per commodity



Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

The contribution of the drivers to the annual global GHG footprint is shown in Figure 40. LUC emissions account for 36% of the total. Soil emissions exceed LUC emissions for our 17 commodities; it accounts for 43% of the total global footprint.

Figure 40 Annual global GHG footprint, driver contribution



Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

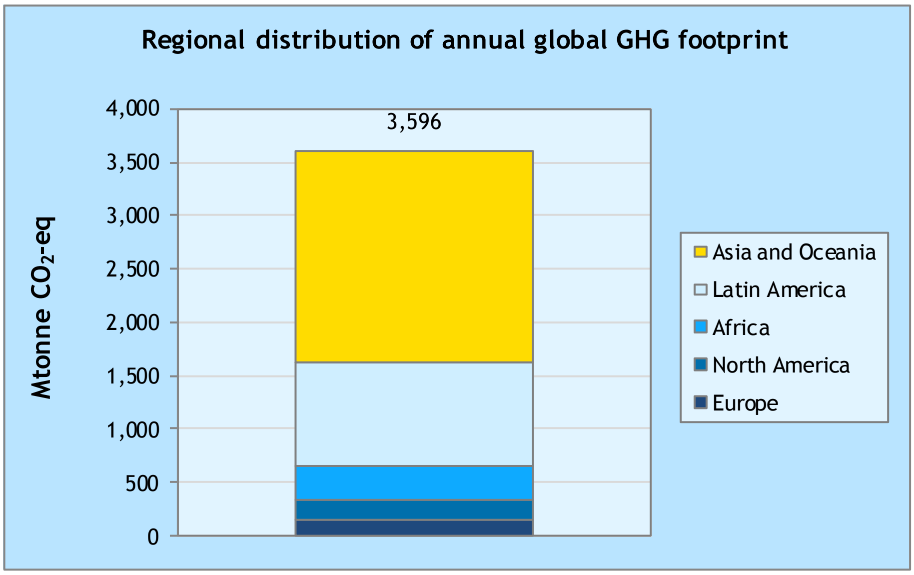
Table 11 Contribution (%) of the drivers to the annual global GHG footprint of our seventeen commodities

	Soil emissions	LUC	Machinery	Fertilizers	Rest
% of global GHG footprint	43	36	8	6	8

Total global GHG footprint

The total global GHG footprint of our seventeen commodities amounts to 3.6 Gigatonne ($3.6*10^9$ tonne).

Figure 41 Total annual global GHG footprint of the seventeen commodities



Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

Table 12 **Regional contribution to global production and to the global GHG footprint, for the seventeen commodities**

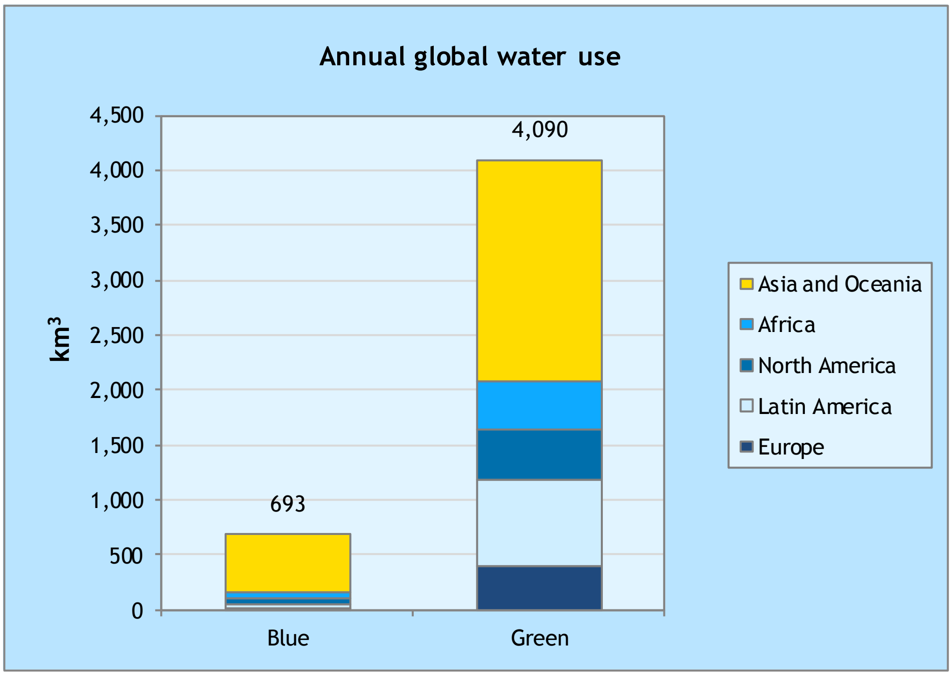
	% of global production	% of global GHG footprint	% of global population
Africa	5	9	15
Europe	9	4	11
North America	11	5	5
Latin America	25	27	9
Asia & Oceania	50	55	60

Compared to the share in total global production (for our seventeen commodities), Africa, Asia & Oceania and Latin America have a relatively high GHG footprint (share in % is higher than share in production). Europe and North America have a relatively low GHG footprint. This can be explained by the data in Figure 39 and Figure 40; LUC emissions are almost zero in Europe and North America, while the other regions also produce most of the commodities with higher soil emissions (rice).

6.3 Global water use

Figure 42 shows annual global water use, for blue water (irrigation) and green water (rainwater). Data on blue water use is used to calculate the water scarcity footprints (Hoekstra, et al., 2012). Of total global annual blue water use, 78% is used in Asia & Oceania. Water use for processes other than irrigation is also included in these figures. This usually contributes little to the water scarcity footprint.

Figure 42 **Annual global water use - green (rainwater) and blue (irrigation water)**

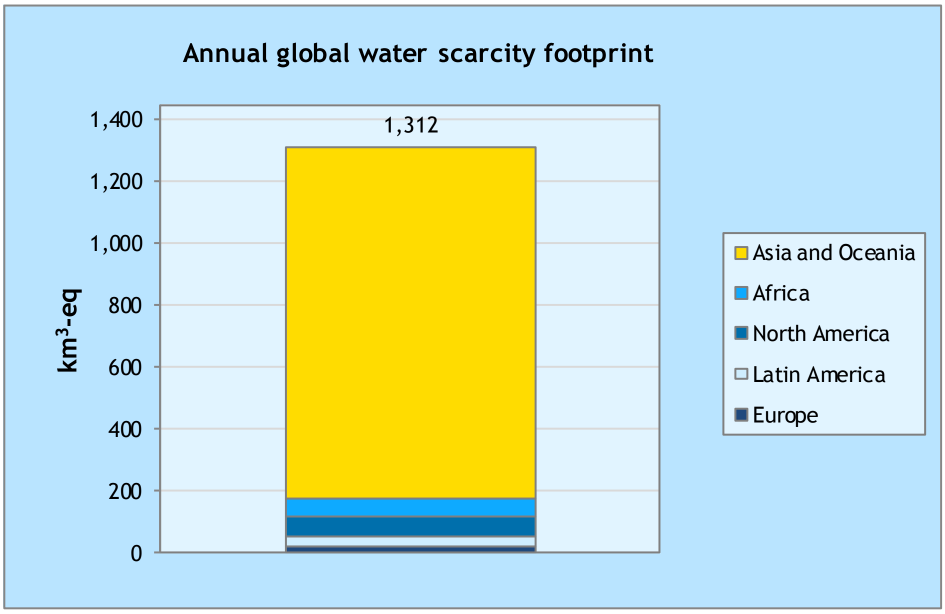


Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

6.4 Water scarcity footprint

Because of the relatively high blue water use (78% of total global water use) and the relatively high water scarcity indicator (1.70, see Table 2), Asia & Oceania has by far the largest water scarcity footprint. Asia & Oceania accounts for 87% of the total global water scarcity footprint for our seventeen commodities.

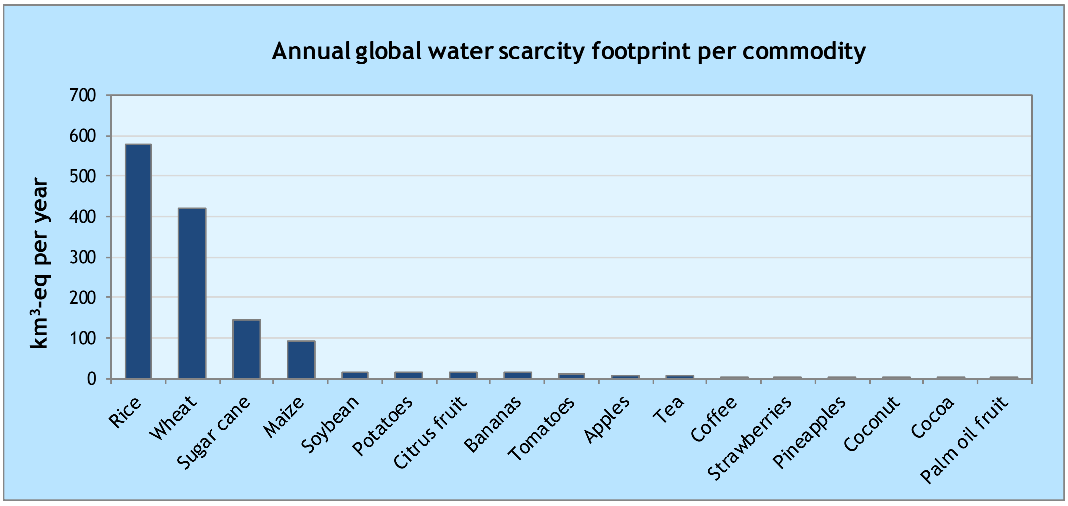
Figure 43 Annual global water scarcity footprint, per region



Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

In Figure 44 the global water scarcity footprints are shown per commodity.

Figure 44 Annual global water scarcity footprint per commodity



Note: For the seventeen commodities included in this study. The data presented concern the agricultural phase of the life cycle.

Rice accounts for 44% of our global GHG footprint, wheat for 32%. The main region for production of these commodities is Asia & Oceania (90% of global rice production, and 49% of wheat production).

6.5 Top commodities

Table 13 lists the top 6 commodities in terms of GHG footprint, water scarcity footprint and production quantity.

Table 13 Top 6 commodities in terms of GHG footprint, water scarcity footprint and production quantity

Commodity	# in terms of GHG footprint	# in terms of water scarcity footprint	# in terms of production quantity
Rice	1	1	3
Soybean	2	5	6
Maize	3	4	2
Palm oil fruit	4	17	7
Wheat	5	2	4
Sugar cane	6	3	1

7 Literature

Blonk Consultants, 2013. *Direct Land Use Change Assessment Tool,* Gouda: s.n.

Blonk Consultants, 2014. *Blonk Agri-footprint,* Gouda: s.n.

CARE, n.d. *Humanitarian Implications of Climate Change.* [Online]
Available at: http://www.careclimatechange.org/publications/global-reports/42-%20humanitarian-implications-of-climate-change=42
[Accessed 15 December 2014].

Center for Global Development, 2014. *Mapping the Impacts of Climate Change.* [Online]
Available at: http://www.cgdev.org/page/mapping-impacts-climate-change
[Accessed 15 December 2014].

EPA, 2014. *Agriculture and food supply.* [Online]
Available at: http://www.epa.gov/climatechange/impacts-adaptation/agriculture.html
[Accessed 20 November 2014].

ESU-services, 2014. *Life Cycle Inventory Analysis of Food Products,* Zürich: s.n.

FAO, 2003. World Agriculture: Towards 2015/2030. In: *World Agriculture: Towards 2015/2030; An FAO Perspective.* London: Earthscan Publications Ltd.

FAO, 2012. *Water withdrawal by sector, around 2006.* [Online]
Available at:
http://www.fao.org/nr/water/aquastat/globalmaps/AquastatWorldDataEng_20121214_Withdrawal.pdf
[Accessed December 2014].

FAO, 2014. *FAOSTAT,* Rome: s.n.

Germanwatch, 2015. *Global Climate Risk Index 2015,* Bonn: Germanwatch e.V..

Hoekstra, A. et al., 2012. *Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability,* http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0032688: PLoS ONE.

IFPRI, 2010. *Food Security, Farming, and Climate Change to 2050,* Washington, D.C.: International Food Policy Research Institute.

IPCC, 2014. *Climate Change 2014: Impacts, Adaptation and Vulnerability, Chapter 7,* New York: Cambridge University Press.

IPCC, 2014. *Fifth Assessment Report, Chapter 11,* s.l.: Intergovernmental Panel on Climate Change.

Mekonnen, M. & Hoekstra, A., 2010. *The green, blue and grey water footprint of crops and derived crop products,* Delft: UNESCO-IHE Institute for Water Education.

Naandanjain Irrigation, 2012. *Tomato - Tomato cultivation in open fields and greenhouses,* Israel: Naandanjain Ltd.

National Geographic, n.d. *Global Warming Effects Map.* [Online]
Available at:
http://environment.nationalgeographic.com/environment/global-warming/gw-impacts-interactive/
[Accessed 15 december 2014].

ND-GAIN, 2014. *ND-GAIN.* [Online]
Available at: http://index.gain.org/
[Accessed 15 December 2014].

Parry, M. et al., 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change,* 14(1), pp. 53-67.

Röös, E., 2013. *Analysing the Carbon Footprint of Food,* Uppsala: Swedish University of Agricultural Sciences.

Smith, P. et al., 2007. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Palnel on Climate Change.* Cambridge: Cambridge University Press.

Theurl, M. C., Haberl, H., Erb, K.-H. & Lindenthal, T., 2014. Contrasted greenhouse gas emissions from local versus long-range tomato production. *Agron. Sustain. Dev.,* Volume 34, pp. 593-602.

UNFCCC, 2014. *Projected impacts of climate change on IPCC world regions.* [Online]
Available at:
http://unfccc.int/essential_background/the_science/climate_change_impacts_map/items/6448.php
[Accessed 15 December 2014].

Union of Concerned Scientists, 2011. *Climate Hot Map.* [Online]
Available at: http://www.climatehotmap.org/
[Accessed 15 December 2014].

Wetlands International, 2014
Data (Search Results)
Available at: http://www.wetlands.org/Home/tabid/37/Default.aspx
[Accessed 15 december 2014]

WWF, 2014. *Impacts.* [Online]
Available at: http://www.worldwildlife.org/threats/effects-of-climate-change
[Accessed 15 December 2014].

Annex A Regions

Table 14 Regions and countries

Africa			
Algeria	Djibouti	Madagascar	Senegal
Angola	Egypt	Malawi	Seychelles
Benin	Equatorial Guinea	Mali	Sierra Leone
Botswana	Eritrea	Mauritania	Somalia
Burkina Faso	Ethiopia	Mauritius	South Africa
Burundi	Gabon	Morocco	Sudan (former)
Cabo Verde	Gambia	Mozambique	Swaziland
Cameroon	Ghana	Namibia	Togo
Central African Republic	Guinea	Niger	Tunisia
Chad	Guinea-Bissau	Nigeria	Uganda
Comoros	Kenya	Reunion	United Republic of Tanzania
Congo	Lesotho	Rwanda	Zambia
Cote d'Ivoire	Liberia	Sao Tome and Principe	Zimbabwe
Dem. Republic of the Congo	Libya		
Asia & Oceania			
Afghanistan	Georgia	Micronesia (Fed. States of)	Solomon Islands
American Samoa	Guam	Mongolia	Sri Lanka
Armenia	India	Myanmar	Syrian Arab Republic
Australia	Indonesia	Nauru	Tajikistan
Azerbaijan	Iran (Islamic Republic of)	Nepal	Thailand
Bahrain	Iraq	New Caledonia	Timor-Leste
Bangladesh	Israel	New Zealand	Tokelau
Bhutan	Japan	Niue	Tonga
Brunei Darussalam	Jordan	Occupied Palestinian Territory	Turkey
Cambodia	Kazakhstan	Oman	Turkmenistan
China, Hong Kong SAR	Kiribati	Pakistan	Tuvalu
China, mainland	Kuwait	Papua New Guinea	United Arab Emirates
China, Taiwan Province of	Kyrgyzstan	Philippines	Uzbekistan
Cook Islands	Lao People’s Dem. Republic	Qatar	Vanuatu
Cyprus	Lebanon	Republic of Korea	Viet Nam
Dem. People's Rep. of Korea	Malaysia	Samoa	Wallis and Futuna Islands
Fiji	Maldives	Saudi Arabia	Yemen
French Polynesia	Marshall Islands	Singapore	
Europe			
Albania	Faroe Islands	Lithuania	Russian Federation
Austria	Finland	Luxembourg	Serbia
Belarus	France	Malta	Slovakia
Belgium	Germany	Montenegro	Slovenia
Bosnia and Herzegovina	Greece	Netherlands	Spain
Bulgaria	Hungary	Norway	Sweden
Croatia	Iceland	Poland	Switzerland
Czech Republic	Ireland	Portugal	The former Yugoslav Republic of Macedonia
Denmark	Italy	Republic of Moldova	Ukraine
Estonia	Latvia	Romania	United Kingdom
North America			
Bermuda	Canada	Saint Pierre and Miquelon	United States of America

Latin America			
Antigua and Barbuda	Costa Rica	Guyana	Peru
Argentina	Cuba	Haiti	Puerto Rico
Bahamas	Dominica	Honduras	Saint Kitts and Nevis
Barbados	Dominican Republic	Jamaica	Saint Lucia
Belize	Ecuador	Martinique	Saint Vincent and the Grenadines
Bolivia (Plurinational State of)	El Salvador	Mexico	Suriname
Brazil	French Guiana	Montserrat	Trinidad and Tobago
British Virgin Islands	Grenada	Nicaragua	United States Virgin Islands
Cayman Islands	Guadeloupe	Panama	Uruguay
Chile	Guatemala	Paraguay	Venezuela (Bolivarian Rep. of)
Colombia			

Annex B Regional differentiation

B.1 Production

The data related to the countries whose production add up to over 80% of the total regional production will be used in the calculations.

$$\mathit{Percentage\ of\ aggregated\ production\ in\ country\ A\ in}\ (\text{Table 15}) = 20\% \cdot 80\% = 25\%$$

Table 15 Fictitious example of the basis for the regional differentiation

	Production tonne per year (FAO data)	% of total production	% of aggregated production in countries covering over 80% of production (country A and country B)
Country A	20.001	20%	25%
Country B	60.000	60%	75%
Country C	9.999	10%	
Region	90.000		

B.2 Yields

The weighted average yield is determined using the countries which cover over 80% of the regional production. A fictitious example is given in Table 16. Country A covers 20% of the total regional production, Country B 60%. This means that Country A covers 25% of the aggregated production of Country A and Country B. The regional average yield is determined by the sum of the multiplication of the % of aggregated production and the country yield.

$$\mathit{Regional\ average\ yield\ of\ fictitious\ example\ in}\ \text{Table 16} = 25\% \cdot 1 + 75\% \cdot 1{,}5 = 1.375$$

Table 16 Fictitious example of the calculation of the regional average yield

	% of total regional production (FAO data)	% of aggregated production in countries covering over 80% of production (Country A and Country B)	Country yields (FAO data)	Regional yield
Country A	20%	25%	1	
Country B	60%	75%	1.5	
Region				1,375

B.3 LUC emissions

The output of the Direct Land Use Change Emissions Tool is given in tonne CO_2 eq per hectare per year. Therefore, the weighted average LUC emissions per region are based on the area under harvest in the countries which cover over 80% of the production in a region. The regional average LUC emissions are determined by the sum of the multiplication of the % of aggregated area under harvest and the country LUC emissions.

$$\textit{Regional LUCemissions of the fictitious example in } \text{Table 17} = 50\% \cdot 1 + 50\% \cdot 2 = 1.5$$

Table 17 Fictitious example of the calculation of the regional average LUC emissions

	% of total regional production (FAO data)	Area under harvest (hectares, FAO data)	% of aggregated area under harvest in countries covering over 80% of production (Country A and Country B)	LUC-emissions (CO_2 eq per hectare per year)	Regional LUC emissions (CO_2 eq per hectare per year)
Country A	20%	10	50%	1	
Country B	60%	10	50%	2	
Region					1.5

B.4 Water

Water use is given in m^3 per tonne of product. Therefore, like the regional average yield, the regional average water footprint is based on the production in the countries which cover over 80% of the total production in the region. The regional average water footprint is determined by the sum of the multiplication of the % of aggregated production and the country water use.

In some cases, no data on water use is reported by Hoekstra (Hoekstra, et al., 2012).

We treat lack of data in the following way:

Blue water

This entails water use for irrigation. In case no data are reported, we assume that irrigation does not take place. This means the country for which no blue water is reported is included in the calculation for the regional average blue water footprint.

$$\textit{Regional blue water footprint of the fictitious example in } \text{Table 18} = 25\% \cdot 0 + 75\% \cdot 10 = 7.5$$

Table 18 **Fictitious example of blue water use calculation**

	% of total regional production (FAO data)	% of aggregated production in countries covering over 80% of production (Country A and Country B)	Blue water footprint (m^3 per tonne, Hoekstra data)	Regional blue water footprint (m^3 per tonne)
Country A	20%	25%	No data	
Country B	60%	75%	10	
Region				7.5

Green water

This entails rainwater use. Because crops need water to grow, we assume that data are missing. In such cases, we assume that the green water for those countries is equal to the unweighted average of the green water use of the other countries (covering over 80% of production in the region) in the region.

$$Regional\ green\ water\ footprint\ of\ the\ fictitious\ example\ in\ \text{Table 19} = 25\% \cdot 1000 + 75\% \cdot 1000 = 1000$$

Table 19 **Fictitious example of green water use calculation**

	% of total regional production (FAO data)	% of aggregated production in countries covering over 80% of production (Country A and Country B)	Green water footprint (m^3 per tonne, Hoekstra data)	Regional blue water footprint (m^3 per tonne)
Country A	20%	25%	No data	
Country B	60%	75%	1,000	
Region				1,000

Annex C Additional info specific crops

C.1 Palm oil and emissions from peat soils

The Direct Land Use Change Assessment Tool (Blonk Consultants, 2013) does not take (organic) peat soils into account. This limitation is related to data availability. Therefore, as a rule, emissions from cultivation on peat soils are not included in the tool. For cultivation of palm oil fruit, however, these emissions are rather important. They are particularly important in South-East Asia, where around 90% of palm oil fruit is grown and where peat soils are a much more prevalent soil than in other regions. Therefore, in the Agri-footprint database, emissions from peat soils are taken into account for palm oil (Blonk Consultants, 2014). In the fall of 2015, Blonk Consultants will release an update of the Agri-footprint database. In this updated version, the emission factor (kg CO_2) for cultivation of palm oil on peat soils will be adjusted. The new emission factor is based on the value given by the IPCC (IPCC, 2006) (Table 5.6 on p. 5.19) for cultivated organic soils in tropical/sub-tropical regions.

Table 20 Emission factor related to soil type (peat soils) for cultivation of palm oil fruit

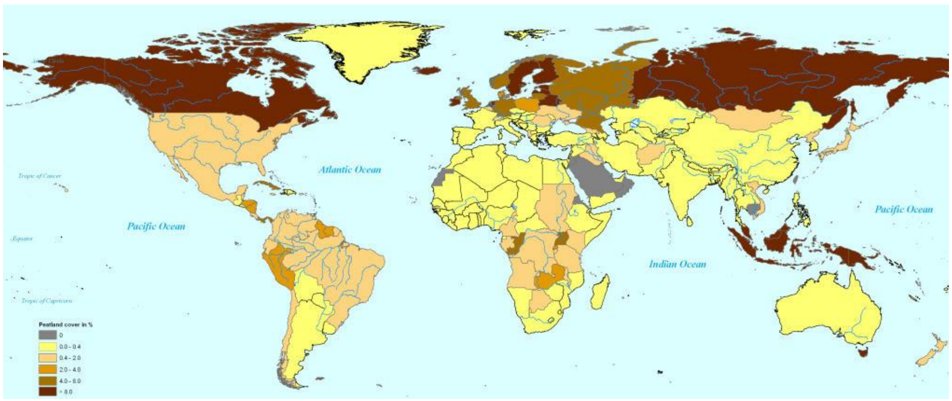
	Tonnes per hectare per year	Relevant for region
Emission factor (CO_2) for cultivation on peat soils	C: 20[a] Converted to CO_2: 73	Asia & Oceania

[a] Source: (IPCC, 2006)

Note: These emission factors are included in the category soil emissions in this study, and apply to part of these emissions.

In this study, emission of CO_2 from peat soils is an issue for cultivation of palm oil fruit in the Asia & Oceania region. Indonesia and Malaysia cover around 94% of total production of palm oil in the Asia & Oceania region. As peatland cover is over 80% in these countries Figure 45) and because palm oil production is increasing in these regions, the probability of use of peat lands is relatively high.

Figure 45 Global peat land cover map (Wetlands International, 2014)



In Table 21 the share of peatlands compared to the total area under harvest for palm oil fruit is elaborated on for the different regions. Palm oil is produced in Africa and Latin America in countries with relatively low peatland cover. Increase in production of palm oil in these regions in the past 20 years is negligible compared to other commodities. Therefore, we assume that cultivation of palm oil fruit on peat soils in Africa and Latin America is negligible. In Asia & Oceania, the share of palm oil fruit cultivated on peat soils is significant (Table 21).

Table 21 **Share of peatlands for palm oil fruit cultivation in the different regions**

Region	Countries in region with high risk of cultivation on peat soils	Country specific data (% of share of palm oil production on peatlands
Europe, North America	No production	-
Africa and Latin America	Peatland cover is low, as well as production of palm oil, increase in production of palm oil is negligible compared to other commodities	-
Asia & Oceania	Indonesia: > 80% peatland cover Malaysia: > 80% peatland cover	30%[a] 11.8% [a]

[a] Source: (Blonk Consultants, 2013) based on data from (Wetlands International, 2014)

As shown in Table 21, palm oil fruit cultivation on peat soils only comprises part of the total area under cultivation. To obtain a weighted average emission factor per 'average hectare' (peat soils + mineral soils) for the whole region, we took the share of the total area under cultivation in Indonesia and Malaysia into account, as well as the shares of cultivation on peat soils in these countries (as elaborated on in Table 22). This yields a regionally differentiated emission factor for an 'average hectare'.

Table 22 **Emission factors per 'average hectare' (average of cultivation on peat soils and mineral soils in the country).**

	Share of production (mass)	Share of area (of sum of ID+MY)	Emission factor per 'average hectare'[a] (mix of peat soils and mineral soils; to be used in LCI)
Indonesia (ID)	50%	59%	21.9 tonnes CO_2 per 'average hectare'[b]
Malaysia (MY)	44%	41%	8.6 tonnes CO_2 per 'average hectare'[c]
Asia & Oceania	94%	-	16.4 tonnes CO_2 per 'average hectare'[d]

[a] Average hectare for ID: 30% peat soils, 70% mineral soils (Table 21)

Average hectare for MY: 11.8% peat soils, 82.2% mineral soils (Table 21)

[b] 30% (Table 21) of 73 tonnes CO_2 per hectare per year (Table 20)

[c] 11.8% (Table 21) of 73 tonnes CO_2 per hectare per year (Table 20)

[d] Weighted average (weighted with share of area under cultivation) of emission factors per average hectare for ID and MY

C.2 Rice and methane emissions

The GHG footprint of rice cultivation is dominated by methane emissions related to irrigation practices. These emissions differ per country, based on different factors related to the water regime during the cultivation period and before the cultivation period, on the application of organic amendments (e.g. straw, compost), on the soil type and the rice cultivar (IPCC, 2006).

In the original Agri-footprint inventory, the methane (CH_4) emissions from rice were 172 kg CH_4 per hectare for production in China. Because this factor is very important to the total footprint, we made a regional differentiation.

For rice, FAOSTAT reports 'area harvested' per year (ha/yr) and 'emissions (CH_4)' per year. These data were averaged for the years 2010, 2011, 2012, for the countries which (aggregated) cover over 80% of the harvested area. Subsequently, country specific emission factors (kg/ha) were calculated by dividing the emissions per year (kg/year) over the harvested area (ha/year), yielding a factor which shows the emissions per hectare (kg/ha). These country specific emission factors were used to quantify regionally specific weighted emission factors. The country share of the harvested area in the regional total was used to weight the emission factors. The results for the five regions are shown in Table 23.

Table 23 Regionally specific emission factors for CH_4 emissions from irrigation, based on (FAO, 2014)

Methane emission (ton CH_4/yr)	Rice
Africa	135
Asia & Oceania	145
Europe	425
Latin America	135
North America	350

C.3 Sugar cane and burning of sugar cane stalks

Emissions from burning sugar cane stalks before harvest were not included in the inventory. This in not an issue everywhere. It can, however, significantly affect local/national GHG footprints. When assessing local situations, this factor could be taken into account.