MSc Program
Environmental Technology & International Affairs

Treated wastewater in agriculture - a framework to analyze its global potential.

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Vienna, 15.10.2019

Affidavit

I, **PHILLIP SEBASTIAN FARBOWSKI, BSC.**, hereby declare

1. that I am the sole author of the present Master's Thesis, "TREATED WASTEWATER IN AGRICULTURE - A FRAMEWORK TO ANALYZE ITS GLOBAL POTENTIAL.", 127 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

treated waste water, agriculture, irrigation, water scarcity, food security, climate change

The aim of this thesis was to establish a framework to assess the global potential of substituting fresh water for agricultural irrigation with treated waste water for that purpose. In order to establish whether there is a potential or not, countries from different climate and socio-economic zones were analysed. Taking a closer look at the dominant crops produced and livestock animals kept a rough estimate of the fresh water demand from the agricultural sector in individual countries could be established. These results were then put into contrast with the volume of waste water treated on a national level in order to determine if a substituting potential towards treated waste water for irrigation was given from a quantitative point of view. Regulations regarding the utilization of treated waste water on an international and domestic level were also analysed and discussed along with the implications of climate change on the present and future agricultural production, allowing for conclusions on food and water security.

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Table of Abbreviations

AEZ – Agro Economical Zones (AEZ)

AMIS – Agricultural Market Information System (AMIS)

BOD_5 – Biological Oxygen Demand after 5 days (BOD_5)

CO_2 – Carbon Dioxide

COD – Chemical Oxygen Demand (COD)

DALY – Disability Adjusted Life Years (DALYs)

ENVI – Committee on Environment, Public Health & Food safety of the European Parliament (ENVI)

EU – European Union (EU)

EUROSTAT – European Union statistics division (EUROSTAT)

FAO – Food and Agriculture Organization of the United Nations (FAO)

GAEZ – Global Agro Economical Zones (GAEZ)

GDP – Gross Domestic Product (GDP)

IIASA – International Institute for Applied Systems Analysis (IIASA)

IO – International Organisation (IO)

IPCC – Intergovernmental Panel on Climate Change (IPCC)

ISO – International Organisation for Standardisation (ISO)

IWMI – International Water Management Institute (IWMI)

JRC – Joint Research Centre of the European Commission (JRC)

K – Potassium (K)

MS – Member States of the EU (MS)

MTH – Master Thesis (MTH)

N - Nitrogen (N)

NPK – Nitrogen, Phosphorus and Potassium (NPK)

OECD – Organisation for Economic Co-operation and Development (OECD)

P – Phosphorus (P)

QMRA – Quantitative Microbial Risk Analysis (QMRA)

SAR – Sodium Absorption Ratio (SAR)

SCHEER – Scientific Committee on Health, Environment, Emerging Risks (SCHEER)

SDG – Sustainable Development Goal (SDG)

SS – Suspended Solids (SS)

TDS – Total Dissolved Solids (TDS)

TOC –Total Organic Carbon (TOC)

TS – Total Solids (TS)

UN – United Nations (UN)

WHO – Word Health Organisation (WHO)

WRI – World Resource Institute (WRI)

YLL – one year of illness of one year of life lost to premature death (YLL)

Acknowledgements

I would like to express my deep gratitude to my supervisor Ass. Prof. Dr. Norbert Kreuzinger, for his patient guidance and constructive critiques over the course of this master thesis and his advice & assistance in keeping my progress on schedule.

My grateful thanks are also extended to my family and friends for their continuous help and relentless support throughout my studies.

"The best way to predict your future is to create it."

Abraham Lincoln

1.) Introduction

Since agriculture is one of the largest emitters of Green House Gases and by far the biggest sector abstracting fresh water in the world (70%), a closer look, into possibilities of reducing these fresh water abstractions for irrigation, must be taken. The substitution towards treated waste water would be beneficial to food security since many geographic areas, suffering from water scarcity, would gain the liberty of using their limited fresh water resources in a much more independent and efficient way.

The aim of this master thesis is to establish water demands for agricultural irrigation and to determine the feasibility of treated waste water for agricultural use. The associated main research question "To what extent can wastewater from municipalities be harnessed to satisfy agricultural and farming water demands?" is reinforced by two sub questions. The sub questions "What is the water demand for agriculture and farming in metropolitan areas?" and "What is the capacity of municipal wastewater output in metropolitan areas?" aiming to provide a more refined approach towards the determination of the fresh water substitution potential in agricultural irrigation systems.

As water already is a key issue for conflicts among many nations, an increase of disputes over water resources is very likely to occur. Nations struggle over access to water resources & use of water and its supply systems as instruments of war, while the fast-growing world population and UN development goals are increasing the competition on limited water supplies. Global changes to climatic conditions will also increase the demand for water, change the irrigation requirements of crops and reshape the availability and quality of fresh water resources unpredictably. *"The Middle East and the Persian Gulf exhibit many vulnerabilities to water related conflict, as do certain countries of Africa, Europe and Southern & Central Asia"* (Gleick, 1993).

Thinking of the Russian and French Revolutions, in 1917 and 1789 respectively, this food-based riots have contributed to social and political change significantly and its tremors are still evident today. One could assume that these revolutions and food related issues are a thing of the past, however since the beginning of the 21st century, uprisings rooting from food related issues, are still taking place and have become a globalized phenomenon where small impacts on one ecosystem can lead to political change on the other side of the globe. Government change in Haiti in 2008, 24 people dead and more than 1500 arrested in Cameroon over food pricing disputes in 2008 and potential food shortages of wheat, rice and other major crops in 2011 in the Middle East are only a few examples (Schneider, 2008). Food shortages are expected to be increasing, since climate change is affecting agricultural production and the exponential growth in the number of people populating the planet exerts substantial pressure on food supply on a global scale. These food shortages will continue to affect food pricing and poses a severe threat to political leadership as occurred in the Arab Spring. The 2011 drought in China for example, had a severe impact on food security in the Middle East and indirectly fuelled social upheaval and a challenge to governance in the entire region, highlighting the globalization of climate change impacts and its interconnections disrupting agriculture, energy and water systems (Sternberg, 2014). The indirect influence of climate change and catastrophes on water, food and populations give these disasters an international scope.

Water related struggles have a much higher capacity of escalating political confrontations and negotiations than violent conflict entails. That's another reason why alternative water resources, such as treated waste water, must be explored in order to reduce the possibility and impact of water related disputes on the world population.

For the purpose of this MTH the three main agricultural crops of different Agro Economical Zones were scrutinized, taking a closer look at the respective water demand on the level of yield maintenance, the variations of water demand throughout the growth stages and the total annual harvest. From these indicators the annual net irrigation water demand was tabulated for the main crops since the conservation of food preferences in the respective societies of analysed geographical zones is a central assumption of simplification regarding the selection of crops investigated. This numbers and growth patterns with their corresponding seasonal variations where be brought into contrast with climate data and its fluctuations throughout the year, such as typical precipitation as natural water supply, soil moisture and days of sunshine using the freely available FAO software CropWat8.0.

Besides agricultural produce, the water demand of livestock framing is also examined by taking a closer look at the 3 predominant farmed animal species in the investigated countries, their average feed water consumption and their typical lifespan, not considering the water required for feed production. From these values, the total annual feed water demand was calculated. To highlight the water intensity of livestock farming the actual feed water demand was put into crop cultivation perspective comparing the water footprint of animal farming to crop production correlating protein and calorie per litre values.

The combined results of the agricultural and livestock farming water consumption were then used as a basis to establish the net demand of fresh water from the agricultural and farming sector, while the whole aim of this Thesis was to establish a framework that's helps assessing if there is a global potential for irrigation using treated waste water to determine possible substitution of fresh water abstraction.

Considering different continents, such as Europe, as one region, one could assume that the circumstances for agricultural production and animal farming must be similar across the continent; quite the opposite is the fact, since the climate zones and typical precipitation values vary significantly even within one and the same country.

In order to establish the quantitative agricultural and waste water output of metropolitan areas, UN and FAO statistics were analysed and thoroughly checked. The implications of Climate Change, the detrimental effects on fresh water resources, the elevated demand for irrigation, feeding animals, the growing world population & land gap and other adjustments needed for sustainable food production and the application of treated waste water as an alternative water source for irrigation are indicated in this thesis. Since most of the crops planted in developed countries, are also consumed “locally”, a change towards more efficient produce would be possible but entails significant lifestyle and food preference changes within the respective population in order to present a feasible substitution of conventional crops, these socio-economic implications will not be discussed in depth in this MTH.

While in some water scarce countries like Australia, Israel, Qatar, Singapore and others, agricultural irrigation using recycled or treated waste water is already well established and common practice, the EU is still far behind in that aspect. Some greenhouse systems in the Netherlands and Spain, especially Almeria and El Ejdio, are already exploring the treatment of waste water and water recycling for irrigation successfully. Since very limited legislation is published and other EU directives are currently under review or development, further scientific research and empiric studies have to be conducted in order to create a basis for consensus in the scientific community. The Council Directive, published on 21 May 1991, addressing urban waste water treatment (91/271/EEC) and the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, respectively provide that “treated waste water shall be reused whenever appropriate”. However, ground water recharging and application of treated waste water in urban green spaces irrigation is still a topic of dispute since very limited experience and consensus among decision makers currently exists.

Almeria & El Ejido (best practice in the EU)

Almeria, an ancient city on the south-eastern Mediterranean coast of Spain, and the cities and villages in its vicinity are blessed with over 3000 hours of sunshine on 320 days per annum literally is Europe’s fresh fruit and vegetable garden. Almeria’s economy is based on greenhouse agriculture, running a, to a certain extent, controversial but highly efficient plasticultre, producing vast amounts of fruit and vegetables, exporting around 70% (Daily Mail, Britain’s vegetable garden, 2013) of its produce all over the EU. In 2016, Spain was ranked 3rd place behind Mexico and the Netherlands, comparing the output of the global tomato production. Exporting around 908 million kilos, representing a share of 60% produced alone in Almeria, worth 960 million Euros, Almeria is the backbone of the European vegetable and fruit industry (hortoinfo.es, 2016).

With 26.000 hectares of greenhouses, Almeria and its neighbouring town El Ejido are the world largest concentrating of greenhouses, covering around 50% of Europe’s total fresh fruit and vegetable demand. In the mid-1980s the area was notorious for its extremely dry climate and barren land. Abundant annual sun hours combined with technological pioneering, imported soil and drip-fed hydroponic systems supplying chemical fertilizers into plastic bags filled with growth substrate / stone wool have been contributing to the areas agricultural success.

The accumulation of white roofed greenhouses is so vast, that researchers from the University of Almeria have found that the sunlight reflected into the atmosphere has an Albedo Cooling effect. While temperatures in the rest of Spain have climbed at rates above global average, the local temperature in Almeria has dropped on average around 0.3 degrees Celsius every 10 years since 1983 (Baldock, 2018).

Solar panels harnessing the abundant sunlight, not only provide shade to skirmishing desertification, but also provide electricity to power the greenhouse farms. Water retention landscaping combined with the advantageous greenhouse micro climate makes the most out of the little precipitation in that area, 200 mm/a, and from the basis towards a sustainable production system. Salt water capture and desalination provide additional fresh water achieving an entirely sustainable system that integrates renewable energy with food and fresh water production on an industrial scale.

This technological pioneering fruit and vegetable production is now shifting towards an increase in bio and organic farming, catering for the shift in European consumer preferences demanding ever more of such produce. The Almeria province already cultivates bio and organic produce on an area of around 2.500 hectares and is expected to double it over the next four years. Where conventional greenhouses plants are raised in stone wool substrate or hydroponic set ups, bio and organic farming regulations of the EU require the crops to be planted on a natural surface such as soil. This green revolution started back in 2007 when conventional producers found biological solutions for the control of pests and pollination. This catalysed the green movement in Almeria and today all tomatoes cultivated in the area are pollinated 100% naturally, rather than using hormones as used to be common practice in the past. However, organic farming is very sensitive to environmental factors and correct soil management and crop rotation are paramount to ensure successful environmentally friendly production methods (hortidaily.com, 2018).

Climate change has the potential to severely affect agricultural production and poses a substantial threat to human populations in areas most affected by the effects of climate change, leading to climate refugees whom will most likely settle in bigger cities in their home country or abroad. The ever-rising numbers of humans populating the planet combined with an increase of people forced to relocate because of climate change impacts puts a heavy burden on existing agricultural production systems. More people in one area will lead to a higher food & fresh water demand. An elevated food demand in return raises the irrigation requirement leading to less fresh water available for human consumption. That's why conventional agricultural production and irrigation systems have to be reconsidered and most importantly, have to become more resource efficient. Greenhouse production systems like in Almeria demonstrate that such improvements are already feasible in Europe but a lack of legislation on a Community level still prevents many MS from actually implementing such regulations, whereas Australia, the USA and Singapore already have such a legal framework in place.

1.1) To what extent can wastewater from municipalities be harnessed to satisfy agricultural and farming water demands?

Data selection criteria and related considerations for simplification.

In order to obtain scientifically coherent and statistically relevant data from a single Organisation, publicly accessible information provided by the UN specialized sub organisations and agencies was deemed to provide a solid reporting scheme of best available data, verified by a recognised authority.

The statistics division of the Food and Agriculture Organization of the United Nations (FAO-STAT) was considered reliable and hence chosen as the preeminent information source. All crop and livestock related data was obtained via the FAOs' access and download platform FAO-STAT, which is freely accessible via the FAOs' official website. Crop statistics are recorded for 173 products, covering a vast selection of crop specific categories: Crops Primary, Fibre Crops Primary, Cereals, Coarse Grain, Citrus Fruit, Fruit, Jute & Jute-like Fibres, Oilcakes Equivalent, Oil crops Primary, Pulses, Roots and Tubers, Treenuts and Vegetables and Melons. Data are expressed in terms of area harvested, production quantity and yield. The objective of the FAOs' data collection effort is to comprehensively cover production of all primary crops for all countries and regions in the world. Area and production data on cereals relate to crops harvested are for dry grain only. Cereal crops harvested for hay or harvested green for food, feed or silage or used for grazing are therefore excluded. Area data relate to harvested area. Some countries report sown or cultivated area only; however, in these countries the sown or cultivated area does not differ significantly in normal years from the area actually harvested, either because practically the whole area sown is harvested or because the area surveys are conducted around the harvest period. The data gathered by the FAO on livestock numbers are intended to cover all domestic animals irrespective of their age and the place or purpose of their breeding. Estimates have been made for non-reporting countries as well as for countries reporting incomplete data. However, in certain countries, data for chickens, ducks and turkeys do not yet seem to represent the total number of these birds. Certain other countries give a single figure for all poultry; data for these countries are shown under "Chickens" (FAOstat, 2019).

As a suitable timeframe, a period of 30 years was determined to be satisfactory, stating the relevant values such as harvested crop areas and number of head of livestock starting from 1987 until 2017. For classification purposes "total harvested areas" are assumed to be equal to the total irrigated areas in the respective countries. Furthermore, the total produce, combining agricultural and farming output, was considered to have been harvested in the selected city larger than 1 million inhabitants respectively. Livestock water demand reflects only the direct, physiological water need of the specific animal type, excluding all water needed for growing food required for animal sustenance.

Population data, gathered via the UN population department, was used to indicate urban areas considerable to be of significant size. Since population growth is happening almost exclusively in cities that are already quite large, a population size of minimum 1 million inhabitants were deemed satisfactory to meet the interpretation of a "metropolitan area". Furthermore, assuming that all agricultural and farming output was produced in the vicinity of the respective urban areas, transportation & storage facilities and an elaborate network of piping, required for delivering the treated waste water to agricultural areas, where it is needed for irrigation purposes, could also be successfully cut out of the equation. World population data was culled from the United Nations Department of Economic and Social Affairs, Population Division report "World Urbanization Prospects: The 2018 Revision, Online Edition." As a suitable timeframe, again, a period of 30 years was tabbed, stating the appropriate values such as a countries and cities population starting from 1987 until 2017. Since a significantly large proportion of agriculture is located close to urban dwellings, a geographical "filter", helping to narrow down potential areas, was established in the form of explicitly focusing on cities with a minimum of 1 million inhabitants.

Since crop and livestock data was only available on a country by country resolution, a way had to be found, allowing to relate country data to individual urban areas. For this purpose, it was assumed that the entire agricultural production of one respective country was produced in the corresponding city investigated to be scrutinized, allowing for actual comparability through a uniform approach.

AQUASTAT data, providing the extent of treated waste water across all geographic regions and individual countries (strongly dependent on individual reporting habits) was harnessed to assess whether or not there is potential for the use of treated waste water in order to substitute fresh water withdrawals for irrigation purposes. The FAO's AQUASTAT, Main Database, was tapped to source data describing the country specific amounts of waste water generated and processed in different countries across the globe. Again the 30-year timeframe was used to gain relevant data, presenting "Treated municipal wastewater (10^9 m^3/year)" and "Produced municipal wastewater (10^9 m^3/year)" rates. For the purpose of simplification, it was assumed that the total amount of treated wastewater in one country was produced in the corresponding urban area larger than 1 million inhabitants respectively.

To calculate crop water requirements and irrigation requirements based on soil, climate and crop data the FAOs' freely available CropWat 8.0 was used. The software further incorporates significant factors such as daily crop water balances, irrigation scheduling and yield response to water, with all calculations following a standardized and fully implemented method. Climate data required for high quality water demand calculation was obtained via the FAOs' own channel the, again free, ClimWat software.

In order to obtain homogeneous meteorology data, all weather and climate information, gathered via ClimWat, was averaged to be consistent across the whole country respectively. This was performed for all countries and geographic areas investigated in this treatise to ensure an overall persistent approach.

Global planting and harvesting dates, even of the same crop, can vary significantly on a global level. To use objective and verified planting schedules, the "Agricultural Market Information System (AMIS)" was used. These schedules are endorsed not only by the FAO but also the World Bank, International Grains Council, OECD, World Trade Organisation, World Food Programme and many other high-level International Organisations. Since many important IO's work with the AMIS, the respective crop planting dates are assessed objective and can also be seen as an international standard.

For an initial pre-determination of geographic regions and countries with a feasible potential for treated waste water use in agriculture, the agricultural crop produce and livestock headcount on a 30 year average was analysed on a regional basis.

Country (and agricultural economic zone) specific data which was retrieved via the FAO-STAT online-portal, from which data regarding crop-cereals and livestock farming was analysed and used to establish the baseline fresh water requirements, which was then correlated to the actual treated waste water output, accounting for the respective local precipitation patterns and soil moisture conditions during the growth period until harvest and typical feed water requirements of livestock until slaughter, the substitution feasibility (freshwater to treated waste water) was derived by dividing the total freshwater requirement by the actual treated waste water output of the corresponding area.

Area related data, especially from Central Asia, Eastern European countries and former Yugoslavia are partly inconsistent due to historical reasons, since these nations attained independence in 1990s and only then individual data reporting was initiated. Some of these countries are still focusing their resources on more relevant projects since reporting can be quite cost and labour intensive.

1.1.1) What is the water demand for agriculture and farming in metropolitan areas?

Analysis of crop water demand on a yield maintenance level

Information gathered regarding crop related data such as harvested areas and production was sourced from the FAO's own statistics department, FAO-STAT. Numbers for crop areas generally refer to harvested areas and relate to crops produced for dry grain only, excluding all agricultural produce intended as green food, hay, feed, silage and grazing. Reporting issues in some areas arise from local deviations in reporting schemes, some nations report sown / cultivated area instead of harvested area. This minor aberration however does not impact the overall result significantly, since the sown or cultivated area and the harvested area in most cases are congruent.

Data sourced from FAO-STAT reflects a time frame of 30 years in order to provide scientifically feasible information. The arithmetic mean of these 30 year datasets was calculated and analysed. From this initial analysis, the three major corps harvested around the globe were identified, showing a significant dominance of about 7 different crop types cultivated for food production.

In pursuit of establishing the irrigation water demand of the crops investigated in different areas, the 3 most abundantly produced crops were scrutinized using the FAO's free software CropWat8.0. Since CropWat8.0 utilizes climate and weather data of specific countries, a meaningful quantitative irrigation water demand could be computed. Countries and their respective results were clustered into zones of similar climate and socio-economic conditions, as set out by the FAO IIASA "GAEZ model". Planting dates were taken from the AMIS crop calendar. In small countries or nations spanning West to East this approach is sensible, since climate variability occurs mainly across latitudes not longitudes. In large countries spanning North to South this approach resulted in fluctuations of actual irrigation water demand, which was compensated by the normalized climate conditions. In order to investigate the crop water demand required for rice cultivation in paddies, the conditions of direct sowing on black clay soil was applied uniformly in all areas investigated. Due to its higher water holding capacity, compared to the FAOs' medium soil used for conventional crops, black clay soil was used to investigate the water demand for rice cultivation in paddies. For critical black clay soil parameters like "maximum water depth" and "water availability at planting", the values 120 mm and 5 mmWD were applied respectively. Furthermore, Oats and Triticale could not be investigated, since CropWat does not supply the relevant crop parameters and intensive research did not produce conclusive results on the respective crop characteristics required for investigation.

Analysis of livestock feed water requirements

Data describing the quantity of and variety of livestock animals farmed around the globe was obtained from official the FAO database. A time span of 30 years of recorded data was used to ensure statistically sound values. The same data base, as was used to find crop related information, was tapped in order to keep information sources as homogeneous as possible, allowing for any deviations caused by data substitution from experts to cancel each other out or at least to be negligible.

In order to highlight the water footprint for farming and raising of animals, nutrient equivalent values were tabulated displaying “calories per litre” of consumed feed water for livestock, which indicates the energy content that can be “harvested” per litre of feed water for livestock production. These values were then put into contrast with “calories per litre” required for crop irrigation on a level of yield maintenance. Although water for growing crops as animal feed was already excluded from the animal water demand it can be seen that traditional livestock agriculture is extremely inefficient on a water consumption vs. calorie (energy) output level compared to a purely plant based energy source.

As for crops, the three major livestock types bred in one geographic zone were analysed and their water demand ascertained. Typical water consumption levels within the same animal species can vary significantly due to many influencing factors. The respective local climate conditions, species, specimen weight & age, water accessibility and season impact the typical volume of feed water an animal requires to sustain health. For reasons of reducing complexity in this framework, all typical animal feed water requirements were averaged on a holistic scale. This evens out different water demand values by one and the same species due to their size, climate conditions, seasonal variability and other influencing factors, assigning one indicative value of typical feed water demand to the respective livestock type.

1.1.2) What is the capacity of treated municipal wastewater output in metropolitan areas?

Analysis of the quantitative municipal waste water treatment plant output by regions

Data relating to the quantitative effluent output of municipal waste water treatment plants, for reasons of data consistency, was sourced from the FAO’s AQUASTAT channel, which provides a vast set of different information regarding all aspects of water utilization. Although data gaps in AQUASTAT information exist, geographical data comparison and comparison over time between individual countries is assured through FAO quality assurance. In order to provide scientifically sound data, information over a time span of 30 years was analysed by scrutinising statistical datasets.

Waste water in the Caribbean, west & Central Africa, the Caspian Sea area, southern and east Asia remains, to a large extent, unthreaded an is directly discharged into water bodies, posing a potential threat to animal & human health and environmental integrity (Figure 1). Municipal waste water usually contains a predictable, fairly equal set of bacteria, viruses and other pathogens on a global comparison. Industrial waste water contaminants on the other hand are unpredictable and are commonly contaminated by heavy metals and other toxins strongly varying by industrial sector and the utilisation of the discharged water within the prior processing regime. The waste water generation (per capita) in urban areas is consistently higher than among rural populations, leading to an increased waste water output in densely populated areas (WHO, 2006). North America, Western Europe and Scandinavia show the highest level of effectively treated waste water and have stringent waste water effluent quality regulations in place, prohibiting the application of treated waste water in conventional agriculture. Mediterranean Europe & Africa and Central & Eastern Europe treat roughly half of their generated waste water before discharging into the environment. Areas where large volumes of untreated waste water are discharged are at risk of polluting essential water sources exploited in order to sustain daily water requirements for drinking, personal hygiene, sanitation, industry and agriculture. If the pollution levels rise, due to increased mixing with untreated waste water, these sources could be lost for human utilisation and furthermore pose substantial threat to the downstream ecosystem.

In Europe a rough total of 3.9×10^9 m^3/a waste water is treated annually, with Western Europe, treating almost two thirds (2.2×10^9 m^3/a) of Europe's total processed waste water output. Followed by Eastern, Southern and Northern Europe treating 6.1×10^8 m3/a, 5.6×10^8 m^3/a and 4.4 10^8 m^3/a respectively (Mateo *et al.*, 2013).

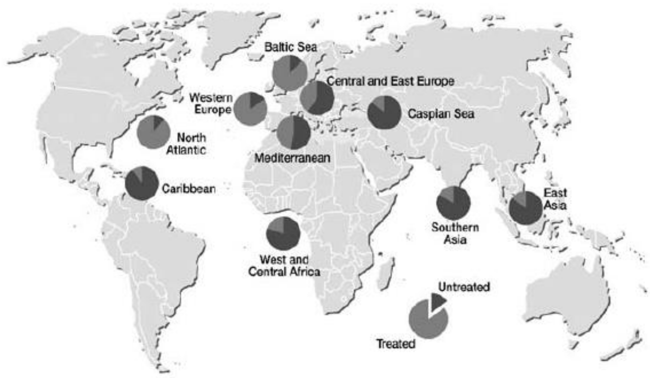

Figure 1: Ratio of waste water treatment

source: Mateo-Sagasta J. et al., 2013

On the whole African continent around 8.8×10^8 m^3/a of generated waste water is treated. Led by Northern Africa where a total of 5.8×10^8 m^3/a is treated, followed by Southern Africa with a combined volume of 2.7×10^8 m^3/a of processed waste water. The waste water output of 3.1×10^6 m^3/a, 3.2×10^7 m3/a and 6.1×10^6 m^3/a treated in Middle, Eastern and Western Africa, respectively, is almost neglectable considering the vast volumes treated in the northern and southern nations of the continent (Mateo *et al.*, 2013).

A similar situation was found to be existing in the Americas with a total volume of treated waste water of 18×10^9 m^3/a. The smallest amount of waste water collected and treated was in Central America where roughly 10% of the generated waste water is treated (2.4×10^7 m^3/a). In the Caribbean 4.9×10^7 m^3/a of urban waste water is treated. The second largest "producer" of treated waste water in the Americas is South

America where 5.4 x 10^8 m^3/a is processed. By far the largest volume of treated waste water in the Americas is produced in Northern America with 17.4 x 10^9 m^3/a (Mateo *et al.*, 2013).

12.9 x 10^9 m^3/a of waste water is treated in Asia, with the biggest contributor being Eastern Asia (11.0 x 10^9 m^3/a) followed by Southern Asia where 7.9 x 10^8 m^3/a of collected waste water is treated. The waste water treatment output in South-eastern Asia is (with 5.6 x 10^8 m^3/a) the third largest volume of treated waste water in the Asian region. Western and Central Asia where 3.2 x 10^8 m^3/a and 1.9 x 10^8 m^3/a of treated waste water is generated respectively are at the bottom of the Asian ranking (Mateo *et al.*, 2013).

Unfortunately, no data, accurate enough for the purposes of this MTH could be obtained for Oceania, including Australia, New Zealand and the associated pacific islands.

As indicated in Figure 1, only about 20% (WWAP, 2012) of the globally generated waste water is actually collected and treated and the exact volume of treated waste water varies significantly around the globe, where western nations are among the most diligent in actually collecting and treating urban waste water. Therefore, the theoretical potential of utilising treated waste water for agriculture is much higher, if the remaining 80% of this untapped resource were actually to be collected and processed.

Analysis of areas with sufficient rain to sustain crop yield

As can be seen in Figure 2 below, average precipitation shows strong variability across the globe. The northern part of South America, the southern part of Central America, the south western tip Africa from Cape Verde over Senegal to Liberia, the western coast of Central Africa, the northeast of Madagascar, India's west coast and the Greater Sunda Islands stretching from the Bay of Bengal to the Solomon Sea are geographic locations that receive the highest amount of rain on the planet with a recorded annual average between 1500 to 2500 mm and exceeding more than 2500 mm (FAO, 2016) in some areas. As around 55% of the gross value of food is produced in rain fed conditions on around 72% of the global harvested crop land (Molden, 2007) and fresh water abstraction by sector is by far the highest (around 70% and increasing) in agriculture, recycled water & treated waste water have to be considered a highly valuable resource since water scarcity is already a global threat.

An average between 500 to 1000 mm of annual precipitation can be collected in the eastern part of the USA and Canada, east Argentina, most parts of Europe east and west Russia, the majority of India, east Australia & New Zealand, east China and Japan. Chiles Pacific coast, the northern territories of Greenland, the Sahara Desert, the latter part of the Arabic Peninsula Namibia's Atlantic coast and the majority of Central Asia's China are among the driest regions in the world where the annual precipitation average is at a low maximum of 100 mm.

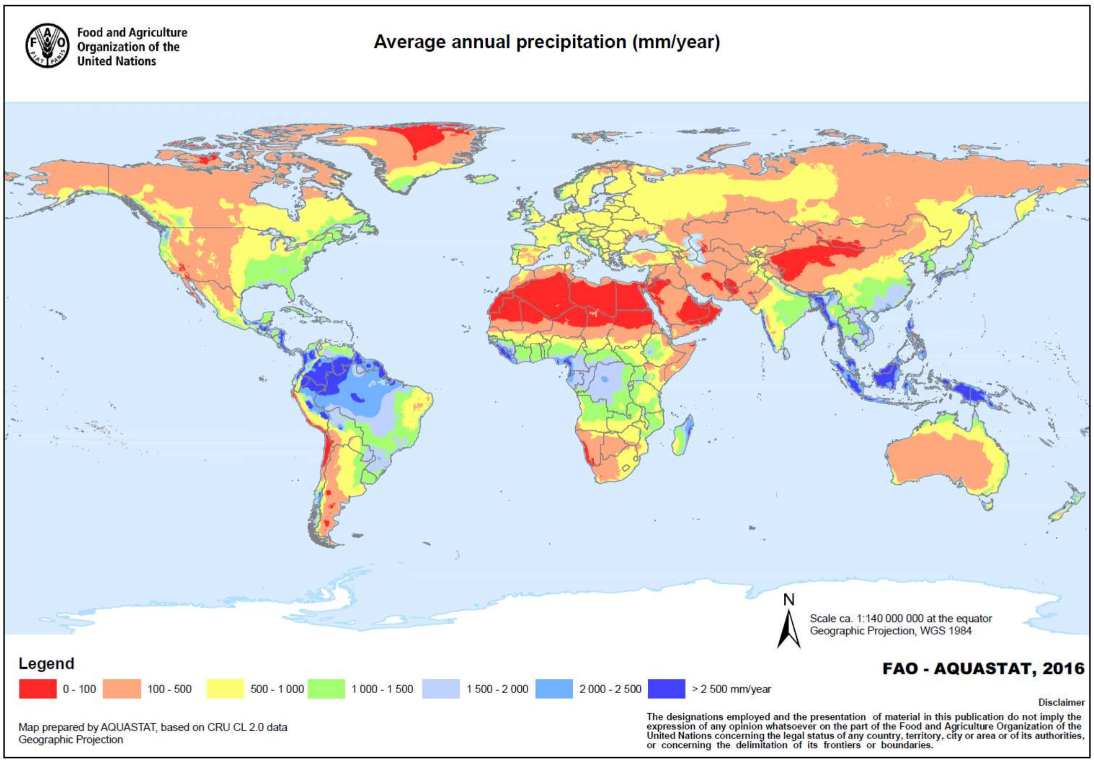

Figure 2: Average annual precipitation

source: FAO, 2016

The overall impact of climate change and the associated changes in precipitation patterns, soil moisture and general water availability are highly complex and show excessive variability among different climate zones. A few general conclusions however are possible to be taken. A higher level of atmospheric CO_2 concentration could lead to higher yields because plants have more Carbon Dioxide available for photosynthesis. CO_2 enrichment is already a common practice for yield maximization in industrialized greenhouse farming systems. Another effect closely linked to climate change is an increased risk of drought which directly leads to a yield depression. The 2003 draught in Austria led to a yield reduction from 12% for wheat to 15% in grassland (Wirsig, 2007) alone. Increased climate variability and extreme weather events leading to temperature and precipitation extremes could increase the risk of overall yield reduction, in particular when looking at climate sensitive agricultural produce such as cereal crops (IPPC, 2014).

2.) Research Chapters

2.1.) State of the Art

2.1.1) Singapore's "NEWater" benchmark

Singapore, an affluent island city state on Asia's Pacific coast, has officially been officially declared a water poor area by the FAO. The countries prosperity and economic development are unable to address Singapore's most pressing issue of not having sufficient fresh water resources to meet the country's needs. Diversifying water sources like importing water from its neighbouring countries, tapping Singapore's above average precipitation (of around 2400 mm per annum) by expanding water reservoirs have proofed to be insufficient. Desalination of sea water is another potential source of water but highly cost intensive and therefore represents only a fraction of Singapore's fresh water sources. All these limiting circumstances led the government to launch the "NEWater" project back in 2003. The water qualified as NEWater is highly purified treated waste water, from toilet to tap. Although recycling and treating waste water is already explored in Scandinavia, Spain, the US and Israel, Singapore has received international attention for their efficient recycling of waste water, not only supplying about a third of the country's water demand but also provides 100% of the water required by the highly specialized resident semi-conductor industry. Singapore's first NEWater plant was opened in 2002 and three more went into operation since, producing 430 million litres of NEWater a day (Duerr, 2013). The majority of that is directly used by industry and rest is mixed with nutrient enriched reservoir water and bottled for human consumption. The bottled NEWater is not commercially available but rather distributed free of charge at large events to help raising awareness and acceptance. Around 5% of Singapore's tap water is sourced from ultra clean high-grade recycled water from their NEWater plants (Duerr, 2013). Several stages of purification remove all suspended solids, bacteria, viruses and other pathogens. Ultraviolet disinfection ensures absolute water purity, which even exceeds FAO safety standards. The highly advanced process allows adjusting the final water "product" according to type specific use parameters ranging from agricultural application over high tech semi-conductor production to absolutely safe drinking water. Singapore has successfully demonstrated that the treatment of waste water is an underestimated, highly valuable water re/source which has become a role model regarding sustainable water policy, while the biggest obstacle for successful waste water policy making remains public acceptance.

2.1.2) Current EU legislation/policy

In 2018 a legislative proposal by the European Commission was initiated, pursuing ways to incentivise the reuse of treated waste water, while ensuring a high level of protection regarding human and environmental health. In the Commissions blueprint to safeguard water resources, issued in 2012, the intention to find "the most suitable EU level instrument to encourage water reuse, including a regulation establishing common standards" was stated. The motion furthermore rests on the 2015 circular economy action plan, which is a strong commitment announcing actions to facilitate water reuse, reaching from a legislative proposal on minimum requirements for reused water for irrigation to minimum requirements for sustainable groundwater recharge. Preventing and significantly reducing water stress is also one of the main targets of the 7th environment action programme, adopted by the EU in 2013. Related initiatives at global level include the United Nations' sustainable development goals (SDGs).

Various opportunities, like increasing water availability, delivering energy savings, reduction in GHG emissions from waste water treatment and contributing to climate change adaption are associated with the reuse of treated waste water. Challenges which arise with an increased use of treated waste water include affordability, an additional need of supply infrastructure and public acceptability, which remains low in regard to human consumption in the EU.

The existing EU legislation does not specify conditions for water reuse but caters for two instruments regarding the application of treated waste water. The Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC) and the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, respectively prove that "treated waste water shall be reused whenever appropriate" and lists water reuse as a possible measure in river basin management programmes.

Besides these two EU Directives, 3 further policy documents dealing with the utilisation treated waste water exist. Back in 2007 the Commission announced a hierarchy of measures that MS should adhere to when managing their water recourses in regard to water scarcity and droughts. In 2011, the roadmap to a resource efficient Europe was launched, setting the ambitious target that waster abstraction should stay below 20% of available renewable water sources. The latest communication by the European Commission, the 2012 blueprint to safeguard water resources announced measures to encourage water reuse. "The Fitness Check of EU Freshwater Policy", also from 2012, identified, among other challenges, water scarcity as one of the main future threats. The document further highlighted that that "alternative water supply options with low environmental impact need to be further relied upon" and that industry stakeholders voiced their concern that the lack of EU regulation on waste water reuse in irrigation, could potentially have adverse impacts on agricultural produce on the single market.

In 2014 the Commission's Joint Research Centre (JRC) in Seville, Spain, had conducted a study *"Water Reuse in Europe - Relevant guidelines, needs for and barriers to innovation"* and published their findings on guidelines, needs and barriers related to water reuse. In 2017 the Joint Research Centre conducted two studies, exploring the application of treated waste water with a wider approach. L. Alcalde Sanz and B.M Gawlik, of the JRC presented their policy recommendation report *"Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge - Towards a water reuse regulatory instrument at EU level"* outlining the minimum quality requirements for waste water reuse (Alcade Sanz et al., 2014) divulged *"The potential of water reuse for agricultural irrigation in the EU: A Hydro-Economic Analysis"* report, providing a profound basis for assessing the strategic priorities for water reuse in Europe and further elaborating their key economic implications which are that locations most suitable for the reuse are where irrigation infrastructure already exists and the necessary additional investments are minor and most importantly that the cost of water reuse should be considered in a broader context including the whole agricultural value chain in respect of possible beneficial impacts of treated waste water reuse in river basin management.

Over the course of an coequal extent of time, 2014 to 2017, a number of studies by external contractors along with two public consultation rounds were launched to gather views and opinions of the public and stakeholders as well as their consensus on favouring an EU legislative framework regarding waste water reuse in the EU & the instruments of water reuse, minimum quality standards. The Commission accentuated that almost ¾ of all entities involved in this process examined treated waste water at least as safe as water abstracted from rivers as it is common practice across the European Union. This as further consolidated by related scientific opinions issued by the EU Scientific Committee on Health, Environment and Emerging Risks (SCHEER), the WHO and Member States of the European Union.

The European Commission then presented three policy options and their respective impact. Out of the three options “a legal instrument with a fit for purpose approach” was found to be most preferable by the Commission. The only critique on this proposal was received from the European Parliamentary Research Service noting that the overall presentations of options and impacts seems balanced, but some sections of the assessment do not hold with the requirements of the Better Regulation Guidelines.

The Commission’s proposal follows the goal of alleviating water scarcity in the EU by increasing water reuse through ensuring that reclaimed water is safe for agricultural irrigation purposes, which in the Commissions view has the highest potential for an intensive use of treated waste water. The proposal further establishes obligations, like different minimum requirements of reclaimed water quality values according to different crop types and irrigation methods, the monitoring of these minimum standards and the establishment of a risk management in regard to potential additional hazards, for the operators of waste water treatment / water reclamation plants, where treated water is supplied to farmers.

Stakeholders from various interest groups, ranging from representatives of farming & agro-business and individual institutions speaking on behalf of water service providers welcomed the European Commission’s proposal, stressing the need for quality criteria when applying treated waste water for irrigation purposes, however instant concerns were raised addressing potential impediments such as extended responsibilities on all levels, especially regarding risk management plans and legal liabilities as well as the proposals sole focus on agricultural irrigation, not addressing the possibilities of ground water recharge. Consumer perception, which is one of the most central obstacles in the utilisation of treated waste water for irrigation purposes in agriculture will be discussed in more detail in the best practice analysis in the subsequent section.

The Committee on Environment, Public Health and Food Safety (ENVI) of the European Parliament discussed the proposal led by Rapporteur Simona Bonafè. It was noted that a provision for ground water recharge was left out deliberately because a common scientific basis among the EU 28 was lacking and a circumvention of ground water minimum standards was to be avoided, lastly the absence of experience with treated waste water in urban areas, such as Golf Courses & Parks was stated as a central driver to the exclusive focus on agricultural irrigation. In the European Council of Ministers, the proposal, with the sole focus on agricultural irrigation, was examined in June 2018 and it got adopted by the European Parliament on February 12, 2019.

2.2.) Crop and animal water requirements

The Global Agro-Ecological Zones (GAEZ) model

Over the past 30 years, the Food and Agriculture Organization of the United Nations (FAO) together with the International Institute for Applied Systems Analysis (IIASA) have developed the Agro-Ecological Zones (AEZ) methodology for assessing agricultural resources and their potential. Considerable advances in IT systems allowed to generate manifold databases with increasing level of details on a global level. This technological advancement paired with better data collection and presentation led to the first global AEZ assessment in 2000 (FAO, u.d.). Since the new millennium started, these assessments have been undertaken and updated periodically, multiplying the issues addressed, general database size and the number of individual results in the system and the focused data is concentrating on five thematic areas:

- Land and water resources, including soil resources, terrain resources, land cover, protected areas and selected socio economic and demographic data
- Agro-climatic resources, including a variety of climatic indicators
- Suitability and potential yields for up to 280 crops/land utilization types under alternative input and management levels for historical, current and future climate conditions
- Downscaled actual yields and production of main crop commodities
- Yield and production gaps, in terms of ratios and differences between actual yield and production and potentials for main crops.

The GAEZ model postulates the agronomic backbone for a vast menagerie of applications including the quantification of land productivity. The GAEZ model results are typically combined for current major land use and land cover patterns and administrative units, land protection status or broad classes reflecting infrastructure availability and market access conditions. With this large amount of data, a new system had to be created to make the data accessible to a variety of users (FAO, u.d.). This classification of Agro-Ecological Zones, as seen in Figure 3, was used for an initial classification of countries and regions into clusters representing similar climate conditions, providing a basis and allowing for data comparison on a coarse scale.

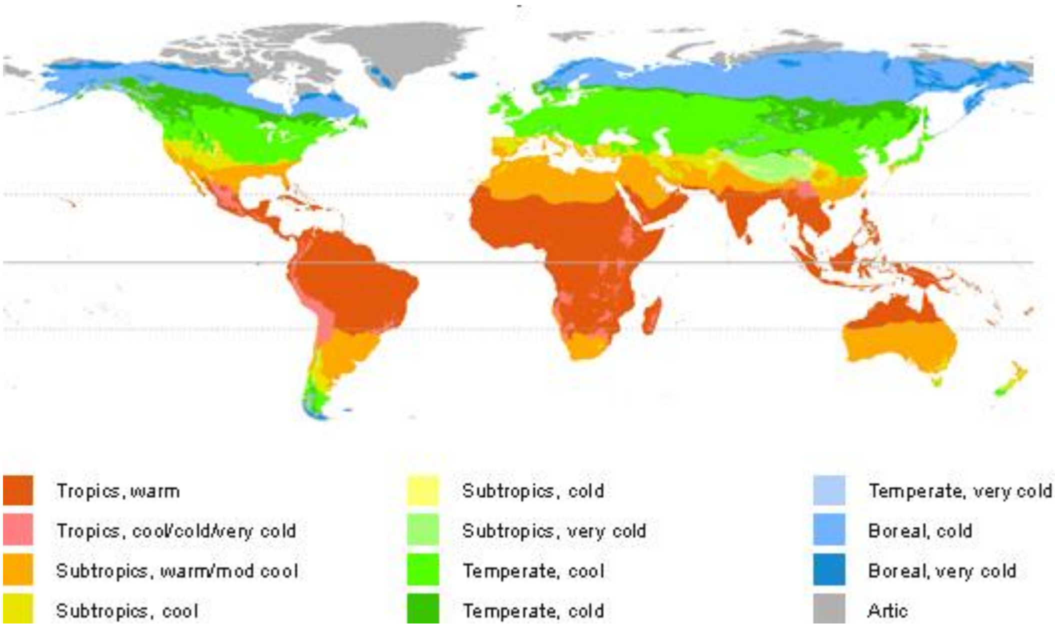

Figure 3: Agro-Ecological Zones according to the GAEZ model
source: http://www.fao.org/nr/gaez/en/#

Climatic and physiological variations such as the extent of annual precipitation, soil moisture, soil type, soil moisture retention and annual hours of sunshine are the underlying factor why crops and animals of one and the same species require significantly different amounts of fresh water for their cultivation and feed respectively among distinct regions of the world. Where rainfall in some zones is sufficient to satisfy the respective crops' water demand, intensive irrigation might be required to grow the same crop under different climatic conditions. The results obtained from the analysis using the FAOs' CropWat 8.0 not only verify but also reinforce the evidence of different fresh water requirements by the same phenotype in contrasting climate conditions.

Farm animal feed water demand

In order to obtain a quantitative estimate of the feed water demand from the livestock producing sector around the globe, FAO data over a time span of 30 years was scrutinized. The most abundantly produced meat on the planet by far is chicken, except in Australia and New Zealand where sheep are the dominant species raised on large industrialized farms. Species for meat production found on most farms are dominated by cattle, pork, chicken, turkey and sheep.

Beef and cattle farming, as indicated in Figure 4, by far require the largest volume of fresh water per head in one year compared to all other farm animals investigated. With more than 14.400 litres/head per annum, beef production exploits almost four times as much fresh water as the second largest consumer of fresh water in the global livestock industry, goats (3.999 litres per annum) do. Taking into consideration that only a fraction of the animal is used for human consumption (10% of the whole animal (cattle) are steak) in fact the whole animal is processed since the value chain is exploited in its entirety with horns & hoofs being used for fertilizer production, skin is utilised in the leather industry and bones are milled to bone meal, which justifies the comparison of water consumption per head between different livestock species. Beef and goat water consumption is closely followed by pork (Swine 3.346 litres) and sheep production (2.613 litres), terrestrial animals demand incomparable higher volumes of fresh water than avian species do. Duck, the most water intensive livestock bird, consumes around 256 litres of fresh water a year. Chicken, the most modest consumer of feed water, requires almost half of the fresh water volume that ducks do and around 20% less than turkeys require annually.

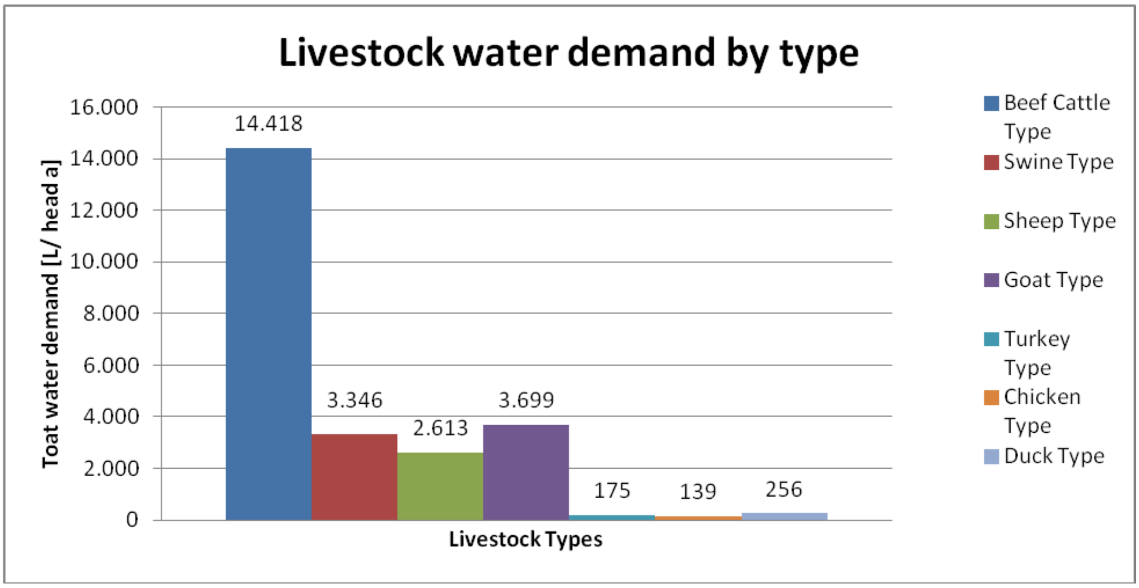

Figure 4: Typical annual livestock feed water demand

Only looking at livestock numbers and their feed water demand is not conclusive when comparing it to the volumes of irrigation water required for conventional crop production. To ensure actual comparability the water footprint was calculated. The typical energy content (kcal) contained in 100g of meat was normalized to the average weight of the animal investigated and then divided by the feed water requirement, resulting in the water footprint given in [kcal/l]. This number was then divided by the headcount of animals of the species investigated and scaled up from litres to cubic meters for better understanding, since irrigation water requirements were also derived in the same unit (m^3). Depending on the extent of animals bred and volume of feed water available, the water productivity or water footprint differs quite significantly, but is generally minute compared to the crop water footprint. The total feed water demand in one geographic location is also directly linked to the animal types kept, simply because distinct animal types consume different amounts of water (Figure 4). As indicated in Figure 5 below, plant-based foods, especially oats, provide substantially higher amounts of energy than meat-based energy sources do. Because animal farming and livestock raising requires vast amounts of feed, which also needs to be grown and irrigated, the water footprint of animals is therefore higher than compared to crops. The water requirements for feed production however are not accounted for in these calculations. Hence energy and protein feed to food conversion efficiencies and potential food security, especially water scarcity and land gap, gains from dietary changes have to be investigated when thinking of “greener” agriculture production systems in the coming future. Even though crop production shows a high degree of variability in production efficiencies, comparing yield data (hg/ha or tons/ha), shows consistently in all geographic areas investigated, that crop production is much more efficient in terms of resource intensity than livestock farming. Meat production in that respect is deemed inefficient, due to the fact that livestock farming not only requires a considerable volume of drinking water for animals, but also water for animal feed & silage production and pasture irrigation. Conversely, the fresh water requirements for livestock farming are some orders of magnitude greater than for conventional crop production.

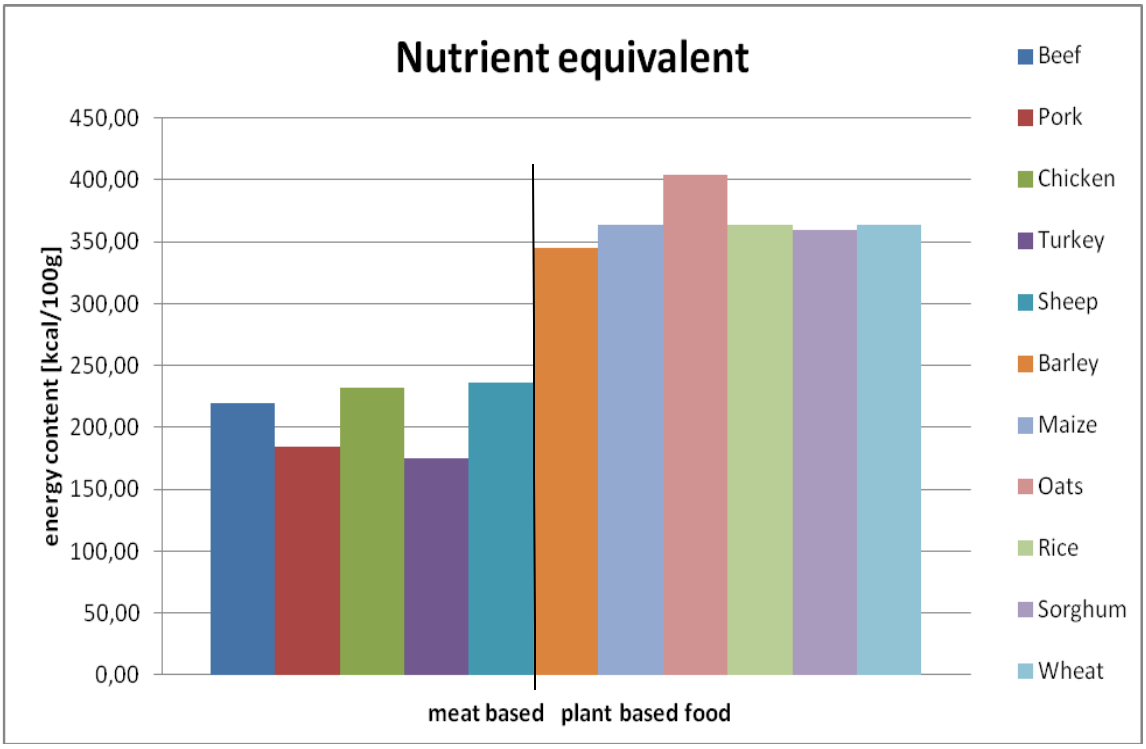

Figure 5: Nutrient equivalent values

Crop irrigation water demand

For the quantitative estimate of the irrigation water requirement of cops cultivated around the globe, FAO data from 1987 to 2017 was analysed, where the irrigation demand represents the actual water requirements by the crop taking the respective local precipitation quantities, according to ClimWat, into account. Determining the 3 major crops produced in the respective regions it was found that the yield, an indicator of productivity, of individual crop types shows strong variability when planted in different areas. This could result from different climate conditions, soil characteristics and technological advancement. For reasons of simplification, soil conditions in this model were assumed to be uniform on all fields investigated, running CropWat simulations with the FAO's medium soil which was already provided by the software. For the determination of irrigation water demand for rice paddy cultivation a different, less permeable soil, with a higher water holding capacity had to be chosen. Again, an official FAO soil, provided through CropWat, black clay was chosen. A single harvest, one growing period, per year was another assumption made in these calculations, since most growth periods would not "fit" into one year, if a second planting would be undertaken.

After the annual production [ha/a], on a 30-year average, was obtained, the 3 major crops were further scrutinized using CropWat8.0. Therefore, the planting and harvesting dates were needed, which were found in the AMIS crop calendar online. Mainly due to different climatic conditions and the associated seasonal shifts, the planting and harvesting of one and the same crop has to be undertaken at different months around the globe. This seasonal variability also influences the yield, since crop water requirements are either met, overshot or under irrigated by natural irrigation and soil moisture in respective locations analysed. The value obtained via CropWat8.0 was the “actual irrigation requirement” which represents the entire volume of irrigation water required additionally, in order to maintain the yield, over the entire growing season. As a result of different climate conditions, already mentioned before, the actual irrigation requirement shows a certain extent of variability across distinct regions in the world.

For example: only comparing the cultivation of wheat across Europe. The actual water requirement of exactly the same crop, wheat, in Northern Europe is around 3.9 x 10^9 m^3/a, where in Southern Europe more than 8.6 x 10^9 m^3/a of irrigation water is needed to sustain the crop yield. In Eastern Europe a volume of roughly 51.6 x 10^9 m^3 per annum is needed, whereas Western Europe seems to be quite efficient, requiring approximately 5.6 x 10^9 m^3 of additional irrigation per season. This variability is also reflected in the value indicating the productivity of the agricultural system, the yield which in return is intimately linked to the water footprint of the respective crop. Sticking to the Wheat in Europe example it can be seen (Annex) that in areas with a low additional irrigation requirement, high resource efficiency, the associated yield (indicating production efficiencies) is also higher than in warm, dry climates with a higher additional irrigation demand. Taking a closer look at production efficiencies of Wheat, Barley and Maize across all regions investigated, it can be seen that the yield [t/ha] of European produce is grown most efficiently, which can be seen in Figure 6.

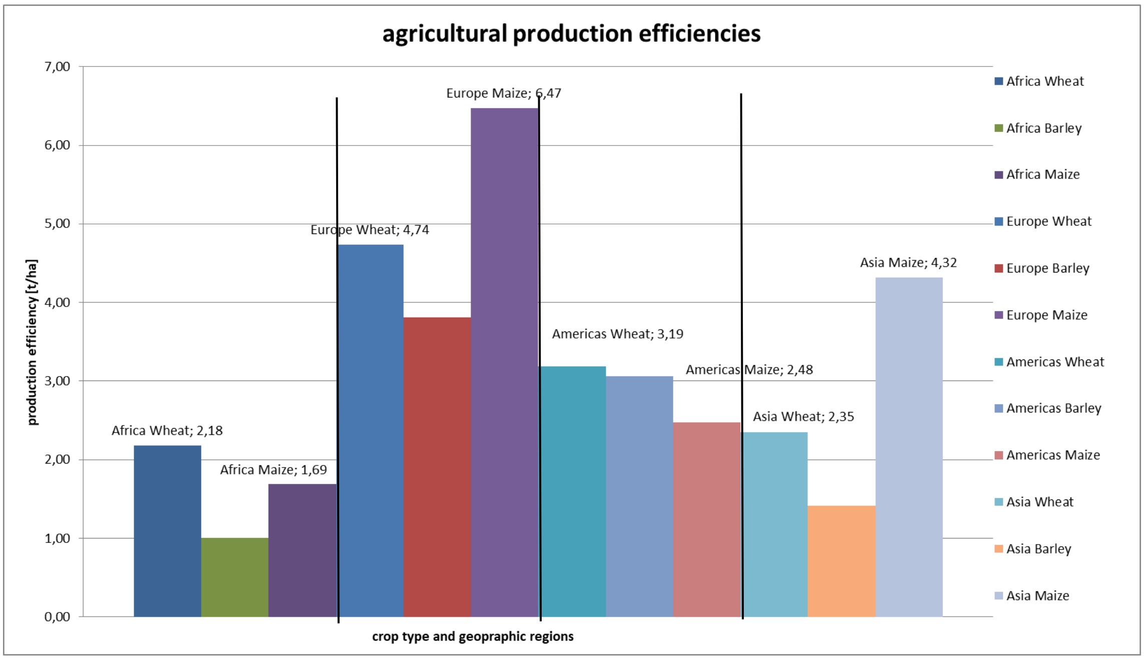

Figure 6: Production efficiencies

Water demand comparison based on average energy intake

Looking at the proportion of waste water, treated and therefore theoretically disposable for irrigation purposes, the percentage of the irrigation demand that could be covered by the available volume of treated waste water was calculated. Assuming that all available treated waste water was used to irrigate only one of the respective cultivated crops in a region, the by far highest value was obtained for the irrigation of sorghum in South East Asia, where about 165% of the irrigation demand could be covered by the available treated waste water. The second and third most feasible situations were determined to be in Western Europe, where roughly 130% and around 93% of the irrigation water demand for maize and barley respectively could potentially be substituted, simply by substituting the fresh water with treated waste water.

Assuming that the average human energy demand lies around 3000 kcal per day, a comparison between a purely plant vs. an exclusively meat-based diet was able to be made, putting the water intensity for the cultivation of the area specific crops into contrast with the crops' energy content (kcal). Taking a closer look on the example of Northern Africa, comparing the dominant crop and farm animal species, wheat, sorghum and barley followed by chicken, sheep and goat in their respective descending order, it was found that wheat and chicken are the most suitable plant and meat for feeding the local population. The irrigation water demand, to feed one person with wheat for an entire year, is with around 630 m^3 (see Annex for global results) significantly lower than a purely chicken based diet which requires roughly 6.340 m^3 of fresh water. Since the calculated results consistently reflect a trophic level increase of a factor of 10, the values obtained are therefore considered to be a reasonable result. This associated trophic level increase factor of 10 entails nutrition conversion efficiency losses of 90%. Analysing water requirements of the second most abundant plant and animal species farmed in Northern Africa, sorghum (~1.380 m^3) and sheep (~6.320 m^3), it was found that the trophic level increase representing a value around 4.6 is considerably lower. This could originate from the fact that conversion efficiencies of ruminants, such as sheep are, are lower due to their intestine structure, where a ruminants' stomach consists of four chambers compared to monogastric animals such as chicken and swine. A similar trophic level disparity, although a little higher (6.8), is the case when comparing the third set animal and plant species, goat and barley. The fresh water demand for goat, again a ruminant, is estimated with around 6.360 m^3 per person a year (based on 3000 kcal daily intake) where the irrigation water requirements, in order to feed a person with Barley are in the region of 940 m^3 per annum.

Waste water potential indicator

As a final step in the calculations the individual water demand for crop irrigation, livestock farming and livestock feed production in the respective investigated areas was combined and put into contrast with the volume of treated waste water in the corresponding area. The obtained result gives the "waste water potential", describing whether or not any location has the potential to supply sufficient treated waste water in order to substitute fresh water abstraction with treated waste water for irrigation purposes. A value above one (1) would indicate a feasible volume of treated waste water would be available for the substation from fresh water for agricultural irrigation Due to the comparably low conversion efficiencies of livestock farming, in contrast to crop cultivation, the partly auspicious substitution potential for crop irrigation was substantially reduced.

Having analysed the "waste water potential" in all geographic locations set out in this framework, it was found that currently the majority of urban areas do not have the capacity to supply sufficient volumes of treated waste water, which would allow a substitution of water sources. Considering the economics capabilities and the connected extent of waste water treatment, a significant rise in the share of processed waste can be expected to rise together with increasing affluence.

Table 1: Continental waste water potential indicators

region	waste water potential
Europe	**0,03**
Africa	0,00
Americas	0,01
Asia	**0,02**
Oceania	**0,02**

Comparing the outcome of the continental waste water potential analysis (Table 1), Europe with a value of 0.03 has the highest potential of shifting towards treated waste water for irrigation, this however only satisfies the water demand for agricultural production to a limited extent. The highest potential within Europe was found to be in Western Europe, representing a value of 0.06. On the African continent, the overall waste water substitution potential was the lowest (0.00), with no significant deviations on a higher regional resolution. The fact that the majority of African nations are among middle & lower and low-income countries, would allow for the conclusion that the associated waste water potential in Africa is projected to grow substantially with rising GDP, and therefore would mark Africa as an area of future interest. Scrutinizing the Americas, it appeared that Northern America, consisting of wealthy Canada and the USA, has the highest potential with a value of 0.04, followed by all other regions on the American continents representing a value of 0.0. Considering that Central & Southern American and Caribbean countries are still their economic development, a significantly higher treated waste water utilization potential is expected to be achievable in the future. Taking a closer look into the five Asian regions, a continental potential of 0.02 was determined. Two regions, Eastern and South Eastern Asia, are among regions with the highest substitution potential globally, representing a value of 0.03 and 0.08 respectively. In Australia and New Zealand, two wealthy nations with most of their population living in many concentrated areas, the overall value shows a potential of 0.02 for substitution from fresh water towards treated waste water for agricultural irrigation.

2.3) Wastewater in communities

Sources of exploitable waste water

Technology available today, total removal of virtually all detectable contaminants of waste water can be removed, this allows for agricultural utilisation of almost all waste water generated worldwide. Despite the technological possibilities to enhance the quality of treated waste water to any desired level, the individual selection of each waste water source is of paramount importance, since many socio-economic implications are intimately connected to the waste water source. Location, the vicinity of the treatment facility to the waste water source and the agricultural areas, quantity, the abundance of waste water available for treatment, and quality, the level / intensity of treatment required are the main cost driving factors in the utilisation of treated waste water for agricultural irrigation purposes (Levi *et al.*, 2011). The quantity of available waste water has to be considered on at least two levels; economies of scale for treatment costs & returns and the amounts of potentially available waste water in the light of the water demand of the respective agricultural and farming products in the area of question. The location is also not to be underestimated, since transportation costs to and from the waste water treatment plant to the area of intended use can rapidly proliferate and exceed the costs of primary fresh water abstraction of rain water collection where possible. Diurnal variation in both fresh water demand for irrigation and waste water availability suggest storage of treated waste water to a certain extent. Furthermore, seasonal variations and different plant growth stages presuppose changes in fresh water demand for irrigation play an important role. Only if these seasonal variation patterns match, an economically feasible application of treated waste water as substitution for primary waste water abstraction can be assured, since no or small, correspondingly inexpensive, compensation reservoirs are needed (Levi *et al.*, 2011). The agricultural water cycle, with many fluctuations in water demand throughout the growth stages and season would require the installation of compensation tanks of significantly large volume if the production of usable treated waste water is constant throughout the year, which clearly is the case focusing on the urban waste water production.

Domestic and industrial waste water

Waste water collected from discharges by residential areas, commercial areas, institutional facilities and surface runoff is commonly referred to as domestic waste water. With minor variations between industrialised countries, economies in transition, developing and least developed countries in terms of chemicals used for personal hygiene and cleaning products, the contaminants and trace elements in domestic waste waters are practically identical around the globe. The mean accumulation of pollutants and impurities is strongly dependent on the water supply per capita, which can vary significantly in different climatic zones. In a combined sewer system, flow rates and pollution levels can skyrocket during extreme weather events. Therefore, a separate storm water sewer would keep the quality of ordinary domestic waste water at a nearly constant level. Unquestionably the waste water quality can therefore vary substantially affecting the complexity, effectiveness and reliability of the waste water treatment system in place (Levi *et al.*, 2011).

Around 20% of the global waste water is generated by the industrial sector, compared to 7% in the municipal sector (Kretschmer *et al.*, 2002), that's why tapping the industrial sector as potential source of waste water for treatment and later agricultural application has to be attentively assessed. The composition and extent of industrial waste water available is depending on the industry and the respective processes involved. The production stage, start up, production, packaging, cleaning and maintenance as well as internal recycling facilities have a significant impact on the abundance and quality of industrial waste water possibly available for treatment and its subsequent use in agriculture. Among all industries, waste water from food processing and domestic waste water have the highest potential for agricultural applications since it contains traces of nutrients beneficial for crop development. Industrial waste water, in contrast to municipal waste water precludes a higher variability of required treatment steps since the contaminants vary significantly among industries. Cooling water, virtually unpolluted, is still highly regulated and poses more of a legal rather than a quality barrier (Levi *et al.*, 2011). Industrial waste water from the metal & mineral mining industry and pulp & paper production contains no nutrients useful for agriculture and therefore needs to be evaluated on a case by case basis scrutinizing the suitability of the effluent.

Untreated domestic waste water, on the condition that all waste water generated by industry is excluded, is characterized by a vast number of typical contaminants, naming only a few ranging from Total Solids (TS), Suspended (SS) & Total Dissolved Solids (TDS), Total Organic Carbon (TOC), Chemical Oxygen Demand (COD) and Biological Oxygen Demand after 5 days (BOD_5) to chemical elements such as the three fertilizers nitrogen (N), phosphorus (P) and potassium (K), Nitrites & Nitrates, Ammonia, Sulfate and Chlorides. The level of contamination (after Tchobanoglous *et al.*, 2003) is classified by the extent of the concentration (Weak / Medium / Strong) of these pollutants, which can be found in Table 2.

Table 2: Typical composition of untreated domestic waste water

Contaminants	Unit	Weak	Medium	Strong
Solids, total (TS)	mg/l	390	720	1200
Dissolved, total (TDS)	mg/l	270	500	860
Fixed	mg/l	160	300	520
Volatile	mg/l	110	200	340
Suspended solids (SS)	mg/l	120	210	400
Fixed	mg/l	25	50	85
Volatile	mg/l	95	160	315
Settleable solids	mg/l	5	10	20
Biochemical oxygen demand, 5-days, 20°C (BOD_5)	mg/l	110	190	350
Total organic carbon (TOC)	mg/l	80	140	260
Chemical oxygen demand (COD)	mg/l	250	430	800
Nitrogen (total as N)	mg/l	20	40	70
Organic	mg/l	8	15	25
Free ammonia	mg/l	12	25	45
Nitrites	mg/l	0	0	0
Nitrates	mg/l	0	0	0
Phosphorus	mg/l	4	7	12
Organic	mg/l	1	2	4
Inorganic	mg/l	3	5	10
Chlorides	mg/l	30	50	90
Sulfate	mg/l	20	30	50
Oil and grease	mg/l	50	90	100
Volatile organic compounds	µg/l	<100	100–400	>400
Total coliforms	no/100 ml	10^6–10^8	10^7–10^9	10^7–10^{10}
Fecal coliforms	no/100 ml	10^3–10^5	10^4–10^6	10^5–10^8
Cryptosporidum oocysts	no/100 ml	10^{-1}–10^0	10^{-1}–10^1	10^{-1}–10^2
Giadria lamblia cysts	no/100 ml	10^{-1}–10^1	10^{-1}–10^2	10^{-1}–10^3

source: (Tchobanoglous et al., 2003)

Raw, untreated, waste water can show agriculturally beneficial parameters, displayed in Table 3, organic matter and nutrients which should, if in line with regulations of the country of application, only be partially removed from the waste water during the treatment. The concentration of these parameters contained in the effluent, however have to be carefully monitored since they have a potentially harmful effect on agriculture if not observed carefully (Levi *et al.*, 2011).

Table 3: Main quality parameters and their significance

Parameter	Significance
Total suspended solids (TSS)	TSS can lead to sludge deposition and anaerobic conditions. Excessive amounts cause clogging of irrigation systems. Measures of particles in wastewater can be related to microbial contamination and turbidity. Can interfere with disinfection effectiveness
Organic indicators	Measure of organic carbon.
Total organic carbon Degradable organics (chemical oxygen demand, biological oxygen demand)	Their biological decomposition can lead to depletion of oxygen. For irrigation only excessive amounts cause problems. Low to moderate concentrations are beneficial
Nutrients N, P, K	When discharged into the aquatic environment they lead to eutrophication. In irrigation they are beneficial, nutrient source. Nitrate in excessive amounts, however, may lead to groundwater contamination
Stable organics (e.g. phenols, pesticides, chlorinated hydrocarbons)	Some are toxic in the environment, accumulation processes in the soil
pH	Affects metal solubility and alkalinity and structure of soil, and plant growth
Heavy metals (Cd, Zn, Ni, etc.)	Accumulation processes in the soil, toxicity for plants
Pathogenic organisms	Measure of microbial health risk due to enteric viruses, pathogenic bacteria and protozoa
Dissolved inorganic compounds, total dissolved solids (TDS), electrical conductivity (EC) and sodium adsorption ratio (SAR)	Excessive salinity may damage crops. Chloride, sodium and boron are toxic to some crops, extensive sodium may cause permeability problems

source: (Levi et al., 2011)

Possibly favourable constituents in raw municipal waste water

Besides the group of NPK (Nitrogen, Phosphorus and Potassium) fertilizers, a moderate concentration of organic carbon and a miniscule concentration of other elements are known to have advantageous effects on depleted soils and therefore, in controlled application on agriculture as a whole. Where fertilizers enrich the soil in essential nutrients, bio degradable organic carbon enhances the water retention capacity and therefore soil moisture, which in return has the potential of increasing the natural water supply for the plant and therefore decrease the irrigation demand significantly. Nitrogen and phosphorus, contained in domestic waste water as a product of metabolic activities is produced at a rate of around 9.4-13.8 gN/person/day and 2.2-4.9 gP/person/day (Beccari *et al.*, 1993), is the most important nutrient in agricultural fertilization aiming at enhanced crop development. However, excessive nitrogen application can lead to inimical effects on the crop, like delayed maturity (prolonging the growth stages) and affect the quantity and quality of the harvest on a whole. The low nitrogen concentrations found in municipal waste water are insignificant in the respect of over fertilizing the soil and crop in question and typically additional fertilization is required to produce a satisfactory harvest. The supplemental application of nitrogen as fertilizer has to be conducted cautiously because excess nitrate can expeditiously leach below the root zone (Feigin *et al.*, 1991) and contaminate the ground water, which is already a great concern in river basin management and can lead not only to damages of human & animal health but also pose a substantial threat to environmental integrity. Phosphorus levels in untreated municipal waste water fluctuate fulminatory on a diurnal basis and typical phosphorus levels are well below crop requirements, not posing any risk of over application when using raw or minimally treated waste water for irrigation. Reflecting on the abundance of nitrogen and phosphorus in domestic waste water, it would be sensible to not treat or at least minimally treat the waste water before application to lower costs of treatment and fertilisation. Since nitrogen and phosphorus are not the only substances found in waste water from urban sources, but many potentially harmful substances are present, waste water treatment is recommended in any case in order to protect human & animal life, the crop and the environment altogether.

Potentially harmful constituents in raw municipal waste water

Viruses, bacteria, protozona and helminth eggs originating from infected human population are the most commonly found pathogens in municipal sewage effluents and pose a considerable threat to handlers of waste water and consumers of crops irrigated with untreated waste water. Besides pathogen removal in the waste water treatment plant, an appropriate irrigation system provides for further treatment that significantly reduces exposure to potentially harmful substances. Suspended solids do not pose a substantial threat to health or the environment, but rather a hazard to the irrigation system itself, since this relatively large particles can easily form together and clog the system. These large particles are also known to be highly abrasive, damaging the irrigation equipment. The crop production can also be harmed by the level of salinity in the soil. Treated waste water contains substances as sodium (Na^+), chloride (Cl^-), bicarbonate, potassium (K^+), calcium (Ca^{2+}), ammonium (NH_4) and sulfate (SO_4) which can cause higher levels of soil salinity, leading to wilting of plants, impairing their development, leading to negative effects on soil structure and permeability. This effect reduces the extent of soil fertility dramatically, calling for treatment of municipal waste water before applied on fields for agricultural irrigation. Sewer effluent constituents as Cl, Na and boron (B) pose immediate toxicity to plants, especially in the case of boron and its effects on deciduous fruit trees. Heavy metals like zinc (Zn), copper (Cu), nickel (Ni), manganese (Mn) and cadmium (Cd) also present a substantial threat due to their toxic properties and longevity. In warm climates with higher evapotranspiration these virulent characteristics can lead to leave necrosis. Heavy metals are not only detrimental to the soil and the crop but also cause severe health issues for consumers of contaminated agricultural products. Contaminants in untreated waste water from municipal sources furthermore include immensely harmful substances like PAH (polycyclic aromatic hydrocarbons), brominated flame retardants and other POP (persistent organic pollutants). Similar harmful pollutants difficult to remove from waste water stem from dissolved pharmaceuticals, detergents and pesticides. Root crops, bulb crops, berries, fruiting vegetable crops and every agricultural produce intended for raw consumption are at much higher risk of bio accumulating substances with adverse effects on consumers compared to cereal crops (Levi *et al*., 2011). Even accounting for UV radiation and its germ-killing capacity, this natural source of disinfection is not a sufficient barrier to protect consumers from adverse effects of bio accumulation of certain substances and waste water treatment prior application on the field for irrigation is therefore rigorously recommended.

2.4) Sensitivity analysis

A sensitivity analysis was conducted in order to gain a better understanding of the method used to establish livestock farming and agricultural irrigation water demands. Minor variations in one of the models' input variables can potentially lead to unexpected outcomes, whether an area has potential to substitute abstracted fresh water with treated waste water or not.

As previously mentioned, the assumption that all food preferences and nutrition habits within the society of the investigated countries and regions will be maintained is fundamental to the research approach taken. A change in nutrition or dietary habits would pose significant threat to food security since a vast majority of agricultural systems is highly specialized on a few crops and industrialized agriculture, which is a major food provider, is not flexible enough to address such changes rapidly.

An increase or decline of the world population, at least in this model, only affects the waste water output of the population and therefore influences the quantity of waste water that could potentially be treated and utilized for irrigation. Since growth in world population is not only associated to a higher food demand, but also entails an elevated drinking water demand, the application of treated waste water for agricultural irrigation could help to ease the stress on fresh water resources while maintaining the capacity of an increased agricultural production. This would also allow abstracted fresh water to be dominantly used as drinking water. Vice versa, a decline in world population would mean a lowered food and drinking water demand, but also less waste water potentially available for treatment and succeeding field application. This hypothetical decline of world population however, can be neglected as the impacts on agricultural production and global food demand go hand in hand. On the other hand, a growing world population would dearly require the utilisation of treated waste water for agricultural purposes since the rise of population numbers not only postulates an increased volume of agricultural production but also a higher demand of drinking water. Furthermore, projections of future world population show a distinct level of disagreement regarding the number of people expected to live on the planet. These discrepancies however can also be overlooked for precisely the same reasons as previously argued.

Except for Africa, changes in annual yield have very little to no impact on the "waste water potential" in this model, since, in many cases, irrigation of crops has to be provided throughout all growth stages. An increase or decrease of the total yield can only be assessed in and after the harvesting period, implications on the total irrigation water demand due to a yield reduction or increase are therefore not existent. Altering the planted crop however, can lead to significant changes of the irrigation water requirements. As some crops have a higher water demand than others, these effects have to be considered in depth on a case by case basis, since the potential of substitution towards treated waste water for irrigation in some geographic areas is marginal.

Any significant, long term alteration of soil moisture can only be caused by climate change. Changes, as effects of global warming and shifts in precipitation patterns & intensities can have adverse effects on the total irrigation water demand in many areas. As can be seen in Figure 7 below (Length of growing period in the 2090s compared with the 2000s), the effects on the length of the growing period, however can be, if only for a few regions, beneficial, since the growing period in that areas is projected to increase up to 20% (WRI, 2018).

2.5) Climate and climate change

The climate, crop type and growth stage of a respective crop are the key influencing factors on any crops water needs. The reference water need presupposes that the crop is cultivated under optimum conditions, allowing it to unfold its full production potential in a given environment. The growth stage of a crop influences the water demand in such a way that a fully-grown crop requires more water than recently planted crops. The crop type impacts the water needs in terms of type specific water requirements e.g.: Maize and sugarcane need more tater than millet or sorghum. A crop grown in a hot climate with lots of sunshine has a much higher water demand than a crop raised in a cool, shady climate (Table 4). Therefore, the most significant factors influential on crop water demand are sunshine, temperature, humidity and wind speed (Brouwer *et al.*, 1986). Thus, climates characterized by hot, dry wind and sunny conditions will inevitably have more stressful effects, in terms of water demand, on any crop than cool, humid, cloudy and calm climates do. Therefore, greenhouses like in Almeria, present a highly attractive way of food production, since key influencing components can be easily and precisely controlled with relatively cheap solutions compared to crops cultivated in the open environment. In greenhouses humidity, temperature and soil conditions are constantly monitored and carefully maintained; wind speed is virtually not present leaving sunshine the only variable influence, which can also be substituted by low energy consuming LED growing lights.

Table 4: Climate effects on crop water demand

Climatic Factor	**Crop water demand**	
	High	**Low**
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Windspeed	windy	little wind
Sunshine	sunny (no clouds)	cloudy (no sun)

source: Brouwer et al., 1986

Aiming to achieve the 2 degree above pre industrial levels goal, set out by the Paris Agreement on climate change, poses a substantial challenge to the global community. Besides fighting climate change, the UN SDGs follow a wide range of equally important targets. The process of achieving any SDG however, should be designed in such a way, that the efforts to mitigate one Sustainable Development Goal may not jeopardize the completion of another SDG. As food security and ending world hunger are definitely high priority agenda items of the UN Development Programme which could potentially suffer from adverse effects by stringent climate change mitigation efforts. Potential negative compromises between climate change mitigation and food security could increase the number of people at risk of hunger by 160 million in 2050 while evading these detrimental repercussions would entail a cost of 0.18 % of global GDP in 2050

(Fujimori *et al.*, 2019). Immediate advantages from mitigation in terms of avoided yield losses could be of considerable importance, further reducing the costs of avoiding these adverse side effects. These qualitative implications call for a careful design of climate change mitigation policies accounting for all expenses arising from agriculture and land prices in respect to food security and other SDGs.

Observed impacts of climate change (Figure 7) can be understood most comprehensively when taking a closer look at evidence of the impact on natural systems. Changing precipitation intensity & patterns and melting of snow & ice are reshaping hydrological systems adversely affecting the quantity and quality of available fresh water resources. Assessing impacts on human systems covering a wide range of geographical regions and crops, leads to the conclusion that negative impacts of climate change on crop productivity outweigh beneficial effects of climate change on agricultural production (IPCC, 2014).

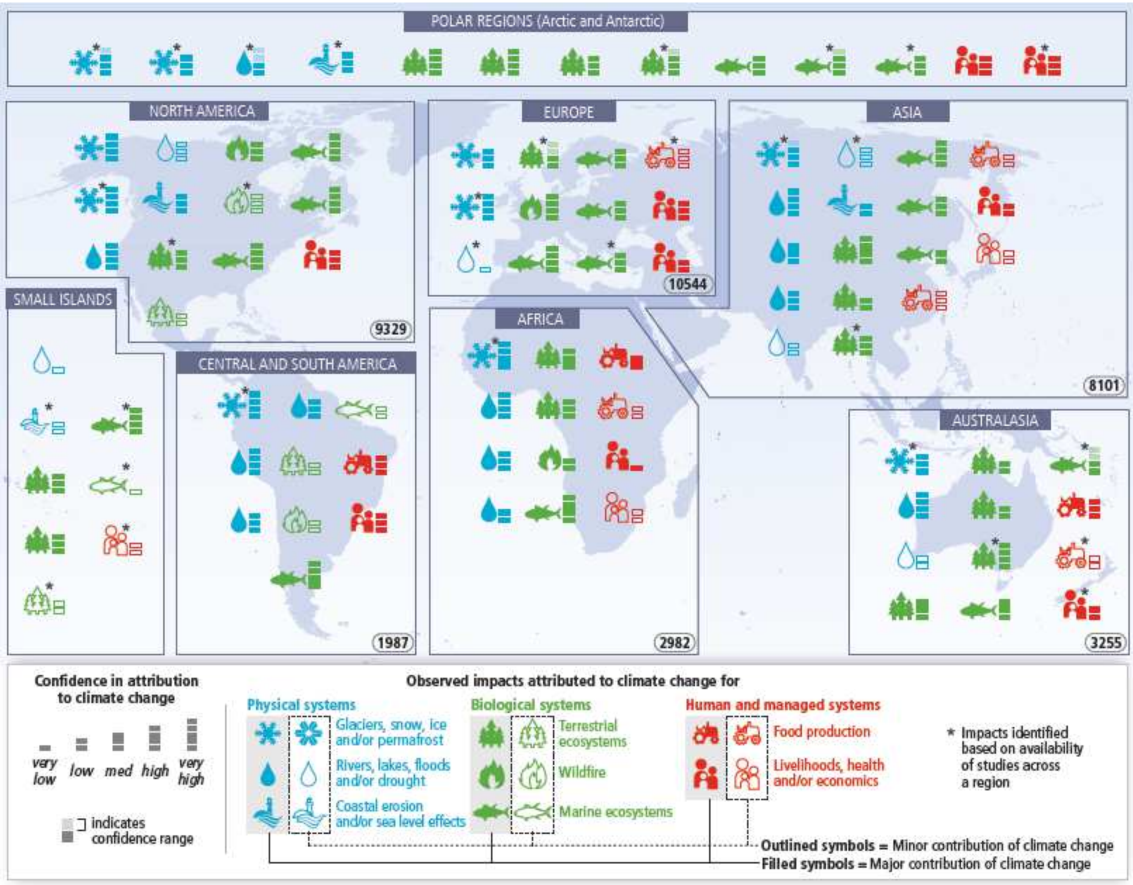

Figure 7: Impacts attributed to climate change

source: IPCC, 2014

Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a growing knowledge base, but publications are still limited for many regions, systems and processes, *highlighting gaps in data and studies. In Figure 7, symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries, grouping related regional scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). These numbers provide an overall measure of the available scientific literature on climate change across regions; they do not indicate the number of publications supporting attribution of climate change impacts in each region. Studies for Polar Regions and small islands are grouped with neighbouring continental regions (IPPC, 2014).*

Economic feasibility is also an important factor when assessing suitable mitigations efforts. Among the most practical mitigation options in land use, with strong regional impact variability regarding cost effectiveness, are reforestation, appropriate forest management, crop & grazing land management and restoration of organic soils (IPCC, 2014). The importance of suitable grazing land management is paramount, since this would allow a significant reduction of the water demand in the livestock farming sector. Properly controlled grazing would allow substitution of water intensive feed crop production with natural pasture, not only reducing the water footprint of meat production, but could also enhance the associated meat quality.

3.) Conclusions

To come back to the original question this thesis is aiming to answer: *"To what extent can wastewater from municipalities be harnessed to satisfy agricultural and farming water demands"*; even though local results differ quite considerably, it is important to highlight the global waste water substitution potential in order to initiate a common policy approach based on science, technology exchange and public acceptance. Not only to alleviate further stress on scarce fresh water resources, but most importantly to provide a higher level of food & water security and independence for the affected population. As waste water reclamation is already common practice in some parts of the world affected by water stress & scarcity, lessons can be learned from Australia, Israel, Singapore, the United States of America and parts of Europe. In areas suffering from fresh water shortages, the substitution of abstracted fresh water for irrigation towards treated waste water is paramount and should be explored, since it would allow more fresh water to be available for direct human consumption and would therefore not only enhance food & water security but also provide a solid foundation for prosperity to thrive.

"What is the water demand for agriculture and farming in metropolitan areas", this sub question could be answered for most cases investigated in the course of this Thesis. Except for two crops, oats and triticale, for which no data was available in the key software utilized, CropWat8.0, to examine actual crop irrigation water demands. The water footprint values that were established for the remaining crops show that irrigation water demand is intimately linked to climatic conditions and crop productivity within the same climate zone and shows a certain degree of variation even within the same climate zone. Any influences from different soil conditions can be excluded since a

uniform soil type was used in the analysis. Feed water demands for livestock animals were derived from the animal head count of individual species and their respective water demand normalized to the average body weight of the particular animal type. Chicken, by far the most abundant livestock animal on the planet, show a much more favourable water footprint than beef does, and a change in dietary preferences among societies towards a higher chicken and lower beef consumption would proof beneficial in terms of feed water requirements, not only because the smaller animal consumes comparably less water, but most importantly it consumes significantly less feed which also needs to be grown and irrigated.

The capacity of treated municipal waste water output, the second sub question established to reinforce the hypothesis, was analysed via the FAOs’ AQUASTAT statistics. Comparing waste water output to actually treated waste water volumes show that this resource has a very high potential, since 80% of collected waste waters remain untreated today. The actually treated twenty percent of treated waste water on a global scale are in most cases equally untapped for agricultural purposes, since legislation regulating the application on fields is either not implemented or still under development. This clearly shows that further development of a legal framework and the actual application are paramount when thinking of ways to improve food and water security in areas struggling to provide sufficient nutrition and drinking water for the local population.

Potential weaknesses in this thesis could arise from data reporting gaps by individual countries. By not fulfilling reporting requirements, a high uncertainty of data validation is present; in some cases, estimates had to be made by the relevant authority, based on historical data combined with data projections. Especially in the case of the FAOs AQUASTAT, recording municipal waste water output quantities and the extent of treated waste water, many reporting gaps were indicated, and estimated data had to be substituted by experts. These expert substitutions present a certain degree of variability, since some potentially influencing factors in their model are either parameterized or based on their experience, which are not always depicting the actual situation accurately.

Taking all of these uncertainties into consideration, the framework to assess the fresh water substitution potential established, could proof highly useful in the field of water resource management, especially in water scarce areas where any opportunity to cut back on fresh water use has to be explored. Furthermore, government ministries, local authorities and decision makers trying to find ways to lower their fresh water abstraction usually have access to higher quality data concerning their own nation, than is publicly available from UN agencies online and can therefore tune this model to perfection by making use of their own, locally verified data.

Potential fields of purposeful future research, based on this framework, include the identification of favourable crop characteristics for engineered crops. Crop science, the modification of conventional crops to suit particular climate, soil and water parameters has a huge potential to provide tailor made seeds for many regions in the world encountering food security and water scarcity issues with ever more evident climate change impacts. Rapid advances in Earth Observation and Remote Sensing lend itself as a potential new way to be harnessed in order to gather accurate information regarding the extent of cropland and crop types around the globe. Regular satellite overpasses also help to track any change on the fields observed, allowing to monitor growth stages and plant health.

Considering the cost of industrial agricultural irrigation, assuming that in Western Europe 1 € is charged per m^3 of treated waste water and around 180 €/ton of Wheat (World Bank) are achievable on the market. The regional Wheat harvest in the affluent region of Western Europe, where also the highest volume of waste water, on a global comparison, is actually treated, over the last 30 years was around 60.630.000 tonnes, which would gain the farmer a return of about 10.913 m€. Subtracting the theoretical expense of ~7.263 m€ for treated waste water for irrigation, the economic gain for the farmer is substantially reduced to roughly 3.651 m€. In mass food production the cultivation of high value crops is already common practice, in such cases the substitution of fresh water with treated waste water could be economically feasible but small farmers, producing niche crops, with a comparably lower value, could probably not afford this substitution with treated waste water since their expenses for irrigation could be higher than their earnings from the harvested yield.

3.1) Conclusions addressing water demand and supply

The water demand, drought sensitivity and typical growth period of any specific crop, as can be seen in Table 5 & Table 6, can vary significantly. The length of the growing period from sowing to harvest is primarily dependent on planting date, climate and crop type & variety. Table 4 above, allows for the conclusion that a cool climate prolongs the growth period of certain crops, hence the impact of climate change on crops in terms of productivity can be seen as positive, since a warmer climate implies a shorter growth period and therefore a lower water consumption. A warmer climate on the other hand entails higher evapotranspiration, leading to a higher water demand. However certain crops already grow “fast” enough to sustain multiple harvests a year. If, due to climate change and its effects on shorter growing periods, it became possible to harvest crops like Maize or Wheat more than twice a year, the water productivity footprint would be lower, but the total water demand for crop cultivation would rise.

Table 5: Indicative crop water need values and drought sensitivity 1/2

Crop	Crop water need (mm/total growing period)	Sensitivity to drought	Total growing period (days)
Alfalfa	800-1600	low-medium	100-365
Banana	1200-2200	high	300-365
Barley/Oats/Wheat	450-650	low-medium	120-150
Bean	300-500	medium-high	75-110
Cabbage	350-500	medium-high	120-140
Citrus	900-1200	low-medium	240-365
Cotton	700-1300	low	180-195
Maize	500-800	medium-high	80-180
Melon	400-600	medium-high	120-160

Source: Brouwer et al., 1986

Table 6: Indicative crop water need values and drought sensitivity 2/2

Crop	Crop water need (mm/total growing period)	Sensitivity to drought	Total growing period (days)
Onion	350-550	medium-high	70-210
Peanut	500-700	low-medium	130-140
Pea	350-500	medium-high	90-100
Pepper	600-900	medium-high	120-210
Potato	500-700	high	105-145
Rice (paddy)	450-700	high	90-150
Sorghum/Millet	450-650	low	120-130
Soybean	450-700	low-medium	135-150
Sugarbeet	550-750	low-medium	160-230
Sugarcane	1500-2500	high	270-365
Sunflower	600-1000	low-medium	125-130
Tomato	400-800	medium-high	135-180

Source: Brouwer et al., 1986

While the crop water demand is fairly linear, only deviating as a result of different stages of growth, the livestock water demand is not as easily established in reality, since water required for livestock food production and animal feed water from birth until slaughter has to be accounted for. Livestock feed and the associated water demand, for cultivating these feed crops, varies significantly among farms, which makes it extremely difficult to formulate the water demand of the livestock industry as a whole, which has not been accounted for in the course of this investigation.

The global volume of waste water treatment is with 20% (WWAP, 2012) quite low, but a firm indicator that the overall potential of this untapped resource is most likely much higher than could be analysed from official FAO data via their own channel AQUASTAT. Showing that presently, treated waste water is a completely underestimated and highly valuable alternative water re/source perfectly suitable for agricultural utilization in many cases.

Furthermore, there are roughly 30.000, known to be edible, plants on this planet from which only 30 are utilized in agriculture. Out of these 30 species, a fraction of 3 different crops absolutely dominates in agricultural production (Longin *et al*, 2016). Due to their relatively high yield, rice, wheat and maize managed to gain such popularity in the food producing industry. Comparing these crops to others such as emmer and spelt, two ancient wheat species, these old wheat types have a much higher energy content than today's' common wheat but have a considerably lower yield and are therefore less attractive and not industrially produced. If such high energy wheat species could be produced more efficiently, leading to equal or higher yields, the effect on food security and resource efficiency would be outstandingly advantageous.

3.2) Conclusions on climate change impacts and mitigation efforts

The impact of climate change on agriculture, food security and nutrition is very complex and presents cascading effects on many dimensions. Effects on ecosystems, such as physical, biological and biophysical, as well as agro ecosystems combined influence the agricultural production as a whole. Quantity, quality and price effects will influence the income of farm households and purchasing power of non-farm households (Figure 8).

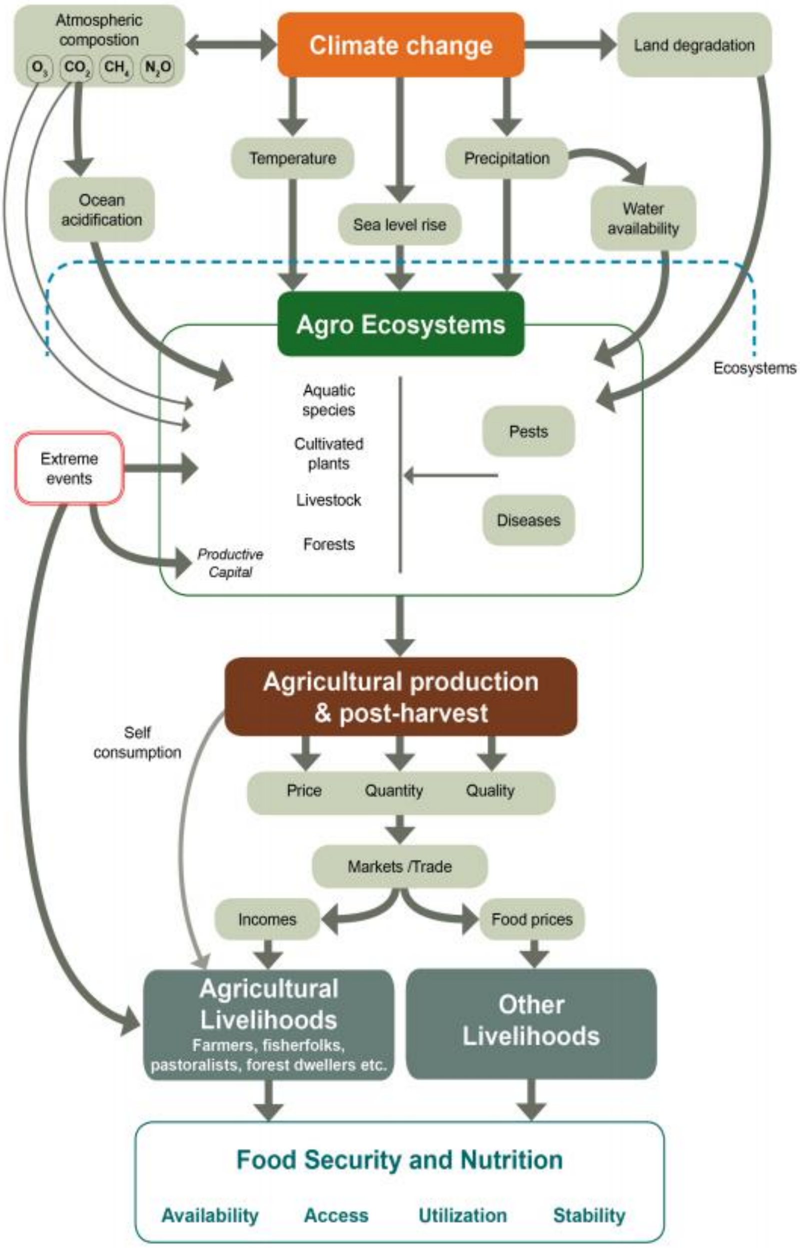

Figure 8: The cascading effects of climate change impacts

source: FAO, 2016

Immediate advantages from climate change mitigation in terms of avoided yield losses could be of considerable importance, further reducing the costs of avoiding adverse side effects emanating from a conflict of interests between certain SDGs. These qualitative implications call for a careful design of climate change mitigation policies accounting for all expenses arising from agriculture and land prices in respect to food & water security and other Sustainable Development Goals.

Climate change adaptation provides the capacity to lower climate change impacts, but is limited in terms of effectiveness, specifically with greater magnitudes and rates of climate change. Sustainable development combined with more immediate adaption actions is also expected to enhance future climate change mitigation possibilities and preparedness in the long run (IPPC, 2014). The IPPCs Fifth Assessment Report (AR5) also highlights that synergies and trade-offs exist between mitigation & adaptation and among different adaptation responses, where interactions occur within and across regions. Enhanced energy efficiently and a switch to cleaner energy sources, leading to emission reductions of air pollutants affecting human health and environmental integrity, a reduction in water and energy consumption in urban areas achieved through greening cities and recycling water, sustainable agriculture and protection of ecosystem services are only a few examples of climate change mitigation actions implying synergy effects.

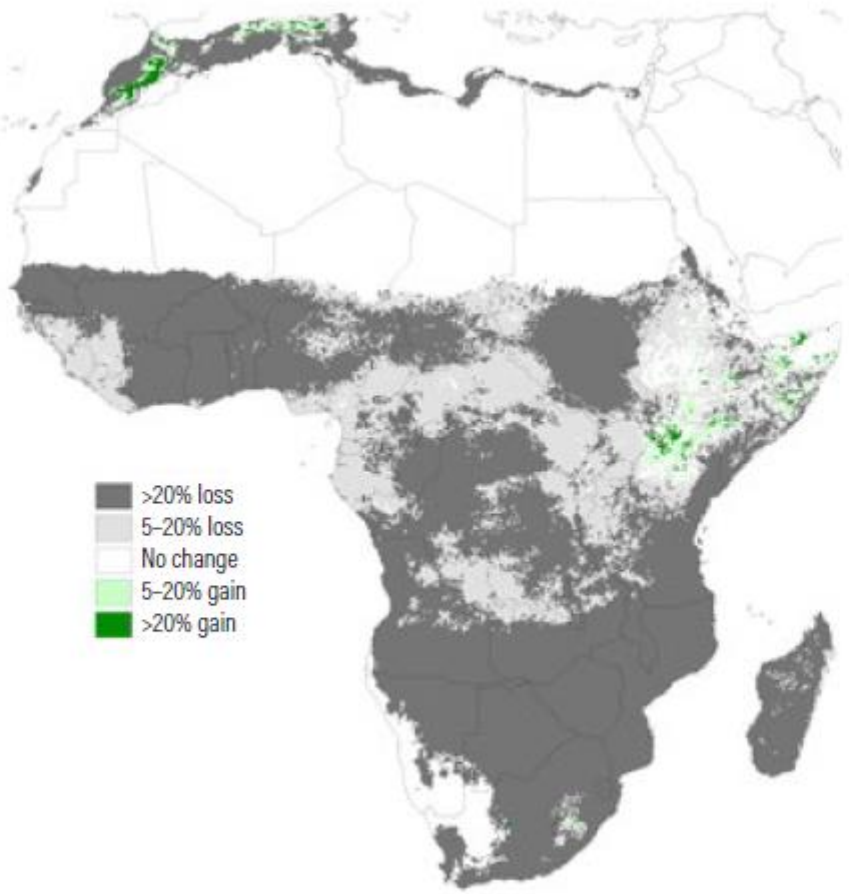

Figure 9: Length of growing period in the 2090s compared with the 2000s

source: WRI, 2018

Furthermore, the implications of climate change could proof beneficial for some crops in the short run as warmer temperatures entail extended growing seasons in countries with cooler climates and a hotter climate shortens the crops growing period from sowing to harvest. Increasing CO_2 concentrations will also impact photosynthesis positively. Deviations in local precipitation patterns and intensity are going to provide more or less water to certain regions, causing either beneficial or adverse effects on the different crops respectively (IPPC, 2014). Other areas, where temperatures are expected rise, will become hotter and drier, therefore harming corps due to drying soils, accelerated water loss and increasing pest damage (Eitzinger *et al.*, 2017), a switch towards treated waste water for irrigation in these areas has to well assessed beforehand, since the salinity hazard poses a substantial threat towards acceleration of desertification in those dry regions. Climate change will also lead to an occurrence of much more extreme weather events, where extensive heat waves harm crop reproduction, especially for maize, wheat & coffee, and growing seasons in certain locations of sub Saharan Africa, Figure 9, can become too short or irregular to sustain the cultivation of crops, posing a substantial threat to local food security (WRI, 2018).

However, the salinity hazard and acceleration of desertification due to irrigation with treated waste water and its effects on potential yield and cultivation area losses have to be carefully balanced and evaluated on a case by case basis, reflecting all considerations of different influencing circumstances in the respective areas.

3.3) Conclusions regarding the food and land gap

Since animal-based foods are more resource intensive than plant-based foods, presenting a higher environmental burden in terms of water consumption, land use change and GHG emissions (Figure 10), a substantial change in food preference and dietary habits needs to happen. Beef and Cattle, in the US alone, cater for only 3% of the total calories produced while occupying half of the agricultural land and emitting 50% of the US' Green House Gas emissions (WRI, 2018). This fact proves that a considerable positive environmental impact would result from an elementary change from beef-based meat consumption towards a more environmentally friendly meat product such as pork or chicken.

If 30% of global ruminant meat consumption would be substituted by plant-based protein, this change alone would close half of the Green House Gas mitigation gap and almost half of the land gap by 2050 (WRI, 2018). Historical changes in consumer preferences like shifts from beef towards chicken are happening in the EU and the US since the 1970s and clearly demonstrate that such an important turnaround is actually possible. Consumption patterns show that an overconsumption of protein occurs across the planet, especially in wealthy regions. Since developing countries and economies in transition are experiencing a rise in local incomes, the associated protein consumption is also climbing beyond levels of daily nutrition requirements. Between 1961 and 2009, animal-based protein available for human consumption flourished by 59%, while plant-based protein availability increased merely by 14% and animal-based food consumption is projected to be growing by 80% until 2050 (WRI, 2018). While individual consumption of animal-based food in industrialized countries is currently at its maximum, transitional economies and developing countries are still growing their animal-based food appetite with increasing wealth and market availability.

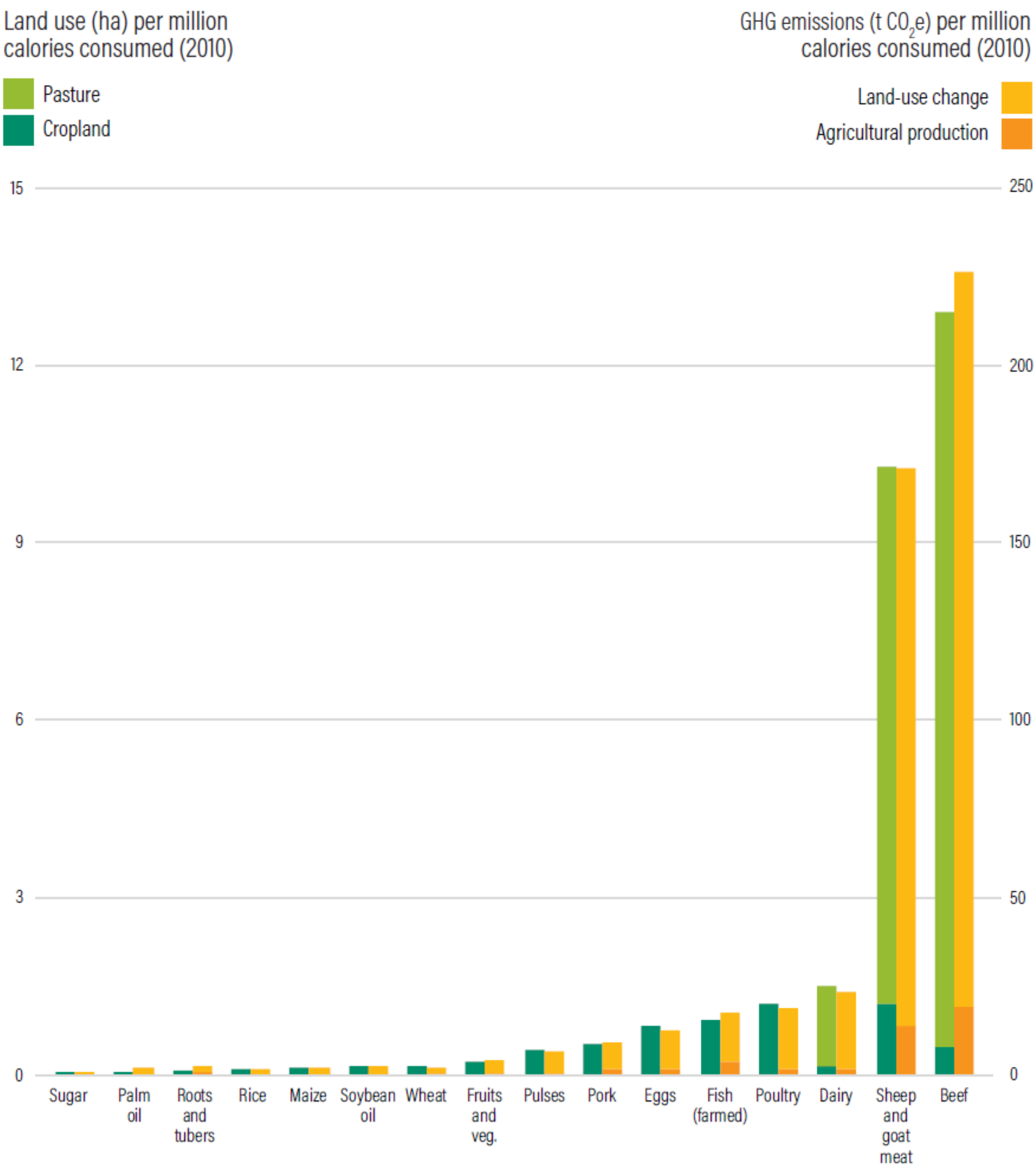

Figure 10: Resource intensity by agricultural production

source: WRI, 2018

Assuming that the water productivity, food and feed production patterns remain unchanged the total amount of water exhausted by evapotranspiration in agriculture is estimated to increase between 70% to 90% by 2050 (Molden, 2007). The 7.000 km^3 of water evaporated by crops today will increase annually by 100-130 km^3, leading to a total increase between 12.000 to 13.500 km^3 by 2050 (Molden, 2007). Additional water required for biomass energy and cotton production is also forecast to increase, to be precise a growth rate of 1.5% annually is predicted in the *"Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture"* report published, in 2007, by the International Water Management Institute (IWMI) based in London. Water productivity and its related footprint have auspiciously developed over the previous decades and predictions attest an ongoing positive projection in the future.

The IWMI report (Molden, 2007) provides a number of different scenarios (Figure 11), elaborating how the future demand of food and fibre can be met with the land and water resources known today.

The “rainfed scenario”, is aiming to achieve an increase in rainfed agricultural production by policy measures such as enhanced soil moisture & supplemental irrigation management, improved soil fertility management, expansion of cropland and a reversal of land degradation.

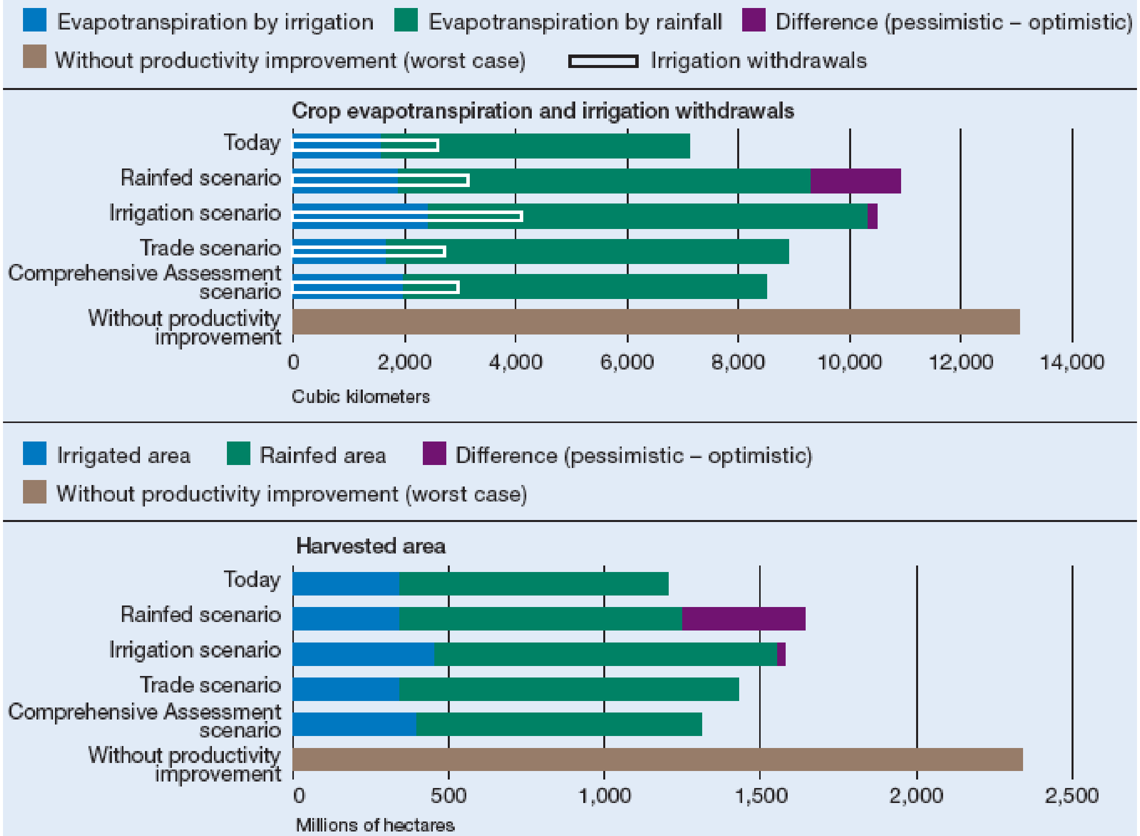

Figure 11: Land and water use today and in the future under different scenarios

source: Molden, 2007

Mitigation efforts encompassed in the second scenario, “irrigation scenario” are aiming at two key elements. Firstly, an increase of the annual irrigation water supply by innovations in system management, development of new surface water storage facilities, an increase in groundwater withdrawals and the use of wastewater. Secondly, an increase in water productivity by integrating multiple users like livestock, fisheries and domestic applications into irrigation systems, adding a higher value to every unit of water consumed.

In the “trade scenario” a reduction of the gross food demand by influencing diets and a reduction of post-harvest losses is envisaged.

Having analysed the global agricultural output and water demand, reflecting especially on the “irrigation scenario”, it can be said that the potential for an increase in irrigation, partly or fully supplemented by treated waste water, is highest in South Asia where around half of the harvested crop area is irrigated and productivity is low. In such a low production area the additional food demand can be easily met by raising water productivity rather than expanding land designated for agricultural production. Quite contrasting is the situation in many developing counties and China, in which water productivity is already comparably high, which limits the scope for further improvements substantially (Molden, 2007). *"Irrigation could contribute 55% of the total value of food supply by 2050. Doubling the irrigated area in Sub-Saharan Africa would increase irrigation's contribution to food supply from only 5% now to an optimistic 11% by 2050"* (Molden, 2007). Assessing these policy scenarios optimistically, an increase of water productivity on already irrigated agricultural area could cover ¾ (Molden, 2007) of the futures additional food demand. In absence of continuous water productivity improvements, the amount of water lost by evaporation in crop production will almost double from the evaporation level of 2000.

At present more than half of the gross value of global food production, cultivated on 70% of the globally harvested crop land is produced under rainfed conditions. While historically many nations focused their efforts solely on irrigation development, their attention should be steered towards upgrading water management practices and improved soil & land management in the future. Considering the capacity of rainfed agriculture on an international level, it's potential could cover the present and future food demand through increased productivity (see Figure 11, "rainfed scenario"). The optimistic outlook of the rainfed scenario builds on a quantum leap in upgrading rainfed agricultural systems, considering only a minor increase in irrigated production, could lead to an average increase of yields from 2.7 tons (metric) to 4.5 tons by the year 2050 (Molden, 2007). With no development of the irrigated crop area, the total area of land used for agricultural production would have to increase by 7%, compared to 24% in the period from 1961 to 2000, in order to assure the ever-rising demand for agricultural produce can be met. Focusing exclusively on rainfed areas entails extensive risks. If farmers are reluctant to adopt new technologies, rainfed yield improvements do not unfold and considering unpredictable climate change alterations, an expansion of the cropped area required to meet the future food demand would be astronomical (around 53% by 2050) and hardly achievable since the available land would then encroach on marginally suitable land, adding to environmental degradation and would lead to land designation rivalries between expansion of urban areas vs. agricultural production areas (Molden, 2007). Regardless of that, rising crop land and water productivity and therefore the capacity of rainfed agriculture would entail dominantly positive effects and would proof sufficient to meet the present and future food demand on a global level, relieving the stress of additional fresh water abstraction.

3.4) Conclusions regarding international standards for treated waste water intended for agricultural use

From the series of epidemiological studies on the health effects of treated waste water in agricultural use, conducted in industrialised nations and developing countries, it is possible to conclude that the following diseases are occasionally transmitted via raw or inadequately treated waste water:

- The general public may develop ascariasis, trichuriasis, typhoid fever, or cholera by consuming salad or vegetable crops irrigated with raw wastewater, and possibly tapeworm by eating the meat of cattle grazed on wastewater-irrigated pasture. There may also be limited transmission of other enteric bacteria and protozoa.

- Wastewater-irrigation workers may develop ancylostomiasis (hookworm infection), ascariasis, possibly cholera, and, to a much lesser extent, infection caused by other enteric bacteria and viruses, if exposed to raw wastewater.

- Although there is no demonstrated risk to the general public residing in areas close to where wastewater is used in sprinkler irrigation, there may be minor transmission of enteric viruses to infants and children living in these areas, especially when the viruses are not endemic to the area and raw wastewater or very poor-quality effluent is used.

The principal problem, as supported by empirical evidence on disease transmission associated to raw waste water irrigation, are hemeniths and limited transmission of bacterial and viral disease. However, a significant majority of transitional economies, using treated waste water for agricultural irrigation, host areas where helminthic and protozoan diseases such as hookworm infection, ascariasis, trichuriasis, and taeniasis, in some areas even cholera, are endemic (Levi *et al.*, 2011). Among populations with low levels of personal and domestic hygiene, an immunisation to endemic gastric viral diseases of children can be expected. Such adverse health effects are only valid in association with the use of raw or inadequately treated waste water of deficient microbial quality laden with pathogens. Therefore, waste water treatment processes, capable of effectively removing virtually all of these pathogens, can and do reduce the detrimental health effects caused by the utilization of raw waste water. In contrast to heminths, which are exceedingly resilient in the environment, bacteria and virus levels decrease rapidly in numbers when filtrating soil or crops. Therefore, meticulous care should be taken of effectively removing heminth eggs, which to a certain extent is less efficient in removing other disease transmitters like bacteria and viruses, when designing the waste water treatment process. These recommended steps are however not universally applicable. Areas with the absence of endemic pathogens, bacteria and viruses as stated above and countries in a comparably advanced stage of development pose a much lower risk to infection. Negative health effects in such areas could possible result from irrigation with raw or only partly treated waste water and pose health risks mainly associated to bacterial and protozoan afflictions. Nevertheless, the underlying strategy of pre-emptive disease control is the same regardless of the prevailing conditions in the respective areas. The concentration of pathogens contained in waste water intended for treatment and its subsequent use for agricultural irrigation must be reduced and the crop selection permitted for cultivation have to be restricted by authorities' action (Levi *et al.*, 2011).

To conclude this section, excessive studies undertaken to evaluate actual and potential risks, to human & environmental health and disease transmission, posed by the irrigation of agricultural produce with treated waste water are much lower than considered by the general public and health representatives of western countries. Early fears of substantial public health risks of gastric disease transmission rooting from waste water irrigation were based on societal and cultural horrors, as well as inexperience and uncertainties associated with human waste products and their agricultural utilisation. What further cemented correlated concerns historically was that pioneering qualitative microbial studies of photogenes originating from, subsequently treated, waste water show the ability to endure the waste water treatment process and remain in the environment, soil and on crops for extended periods of time. These early studies often neglected to assess that the microbial concentrations were dramatically diminished, intermittently to levels much below that required as an infectious dose, in the environment (Levi *et al*., 2011). Present studies and critical peer review by the scientific community, complemented by abundance of available epidemiological evidence conclude the absence of any disease transmission by crops irrigated with treated, and even partly treated, waste water.

Since the bio accumulation hazard is more imminent on agricultural produce intended for raw consumption by humans, accounting for all reservations regarding the protection of human health, it can be said that the potential health risks associated with treated waste water in irrigation can be largely neglected when focusing on the utilisation of treated waste water for irrigating feed crops intended for livestock farming, which are crops processed after harvest & before feeding and are therefore providing another layer of food safety.

However, expanding or creating new legislative acts dealing with treated waste water not only focussing on agricultural irrigation, but equally important on ground water recharge and the utilization of treated waste water in urban green spaces, ensuring a broad scope of application would be a decisive step toward alleviating water stress.

3.5) Considerations on the requirements of treated waste water

Standards for treated waste water intended for agricultural use according to the WHO

The third edition of the guidelines for safe use of waste water, excreta and grey water in agriculture, published by the World Health Organisation (WHO) in September 2006, was intended to support the relevant national entities in establishing domestic standards and guidelines dealing with the use of treated waste water. The guidelines are however not that easily deciphered into tangible numerical values for policy makers and engineers involved and leave room for some uncertainty since they are to be used as a reference document of good management practices regarding the safe use of treated waste water with minimal risks to human health, even if the irrigated food is consumed uncooked (Mara and Kramer, 2008). The rules and standards regulating the use of treated waste water for agricultural irrigation have evolved with a distinct roller coaster type pattern. Cycling from virtually no regulation and control around the 1850s to relentlessly rigours restrictions, which were primarily based on aesthetic considerations from the society & fear of the unknown through the early 20th century (Levi *et al*., 2011), which were later replaced by the interests of the waste water treatment equipment manufacturing industry, to the latest (3rd) edition of the WHOs' guidelines which were established on a scientific basis, recognising the results of epidemiological studies and quantitative microbial risk assessments, focusing on a rational and cost effective approach supporting other United Nations agencies goals such as promotion of personal hygiene, provision of adequate drinking water & sanitation and other healthcare issues. The third edition of the WHO guidelines for safe use of waste water, excreta and grey water in agriculture focuses on aspects relevant in the field, rather than a laboratory, directing their attention on how many pathogens can be ingested in the case of restricted irrigation, with waste water contaminated soil or, in the case of unrestricted irrigation, with waste water irrigated food, without the resulting infection and disease risks being unacceptably high (Mara and Kramer, 2008), where a list of typical waste water contaminants and their respective disease transmitters can be found in Figure 12.

Waterborne bacteria	Salmonella sp, Vibrio cholerae, Legionellaceae
Protozoa	Giardia lamblia, Cryptosporidium sp
Helminths	Ascaris, Toxocara, Taenia (tapeworm), Ancylostoma (hookworm)
Viruses	Hepatitis A virus, Rotaviruses, Enteroviruses

Figure 12: Pathogens associated with municipal waste water

source: UNEP & GCE, 2004

Health risks associated to the use of treated waste water for agricultural purposes, as visualized in Figure 13 below, are primarily gastro intestinal infections caused by viruses, bacteria and protozoan & metazoan parasites. The disease burden of correlated diarrhoeal diseases caused by excreta related pathogens is estimated to be 62 million Disability Adjusted Life Years (DALYs) (Bos, 2006), which are a measure of the health of a population or burden of disease due to a specific disease or risk factor and attempt to measure the time lost because of disability or death from a disease compared with a long life free of disability in the absence of the disease (WHO, 2006). Since one DALY loss measures the equivalent of one year of illness of one year of life lost to premature death (YLL) the DALY is an important indicator for comparing impacts on human health because they account for not only acute health effects but also for delayed and chronic effects, including morbidity and mortality (Bartram *et al.*, 2001). Thus, when risk is described in DALYs, different health outcomes (e.g., cancer vs. giardiasis) can be compared and therefore allow risk management decisions to be prioritized (WHO, 2006).

In order to ascertain the reduction of pathogens required to protect human health the Quantitative Microbial Risk Analysis (QMRA) is applied. Assuming the worst case scenario of employing unrestricted irrigation of agricultural produce intended for raw consumption, the tolerable risk of infection, the design risk, and the consumer exposure to pathogens is calculated using parameter values found in the QMRA equations. The required pathogen reduction represents the maximum dose of rotavirus contamination, in 10mL of treated waste water remaining on the produce at the time of consumption, to keep within the maximum tolerable infection risk (WHO, 2006). The required pathogen reduction in log units can be interpreted as the reduction of rotaviruses contained in 1 litre of untreated waste water, equivalent to the reduction of 1 level of acidity on the pH scale.

Group exposed	Health threats		
	Helminth infection	**Bacteria/viruses**	**Protozoa**
Consumers	Significant risk of *Ascaris* infection for both adults and children with untreated wastewater	Cholera, typhoid and shigellosis outbreaks reported from use of untreated wastewater; seropositive responses for *Helicobacter pylori* (untreated); increase in non-specific diarrhoea when water quality exceeds 10^4 thermotolerant coliforms/100 ml	Evidence of parasitic protozoa found on wastewater-irrigated vegetable surfaces, but no direct evidence of disease transmission
Farm workers and their families	Significant risk of *Ascaris* infection for both adults and children in contact with untreated wastewater; risk remains, especially for children, when wastewater treated to <1 worm egg per litre; increased risk of hookworm infection in workers	Increased risk of diarrhoeal disease in young children with wastewater contact if water quality exceeds 10^4 thermotolerant coliforms/100 ml; elevated risk of *Salmonella* infection in children exposed to untreated wastewater; elevated seroresponse to norovirus in adults exposed to partially treated wastewater	Risk of *Giardia intestinalis* infection was insignificant for contact with both untreated and treated wastewater; increased risk of amoebiasis observed with contact with untreated wastewater
Nearby communities	*Ascaris* transmission not studied for sprinkler irrigation, but same as above for flood or furrow irrigation with heavy contact	Sprinkler irrigation with poor water quality (10^6–10^8 total coliforms/100 ml) and high aerosol exposure associated with increased rates of infection; use of partially treated water (10^4–10^5 thermotolerant coliforms/100 ml or less) in sprinkler irrigation is not associated with increased viral infection rates	No data on transmission of protozoan infections during sprinkler irrigation with wastewater

Figure 13: Summary of health risks associated with the use of waste water for irrigation

source: Bos R., WHO, 2006

Since the updated version of the 1989 WHO guidelines for safe use of waste water, excreta and grey water in agriculture not only include considerations on existing public health and socio economic but also environmental circumstances it is hoped that this new approach encourages the development of controlled waste water reuse for the benefit of mankind, while providing an appropriate level of health protection (Mara and Kramer, 2008).

Monitoring and validation guidelines of the WHO are aiming to assure safe waste water use and protection of health and the environment. The QMRA analysis and low acceptable DALY values which are based on research of indicator organism and pathogen removal by waste water treatment processes, irrigation systems and environmental factors clearly highlight the WHOs' holistic approach towards enhancing human and environmental heath while seeking ways of reducing fresh water abstraction and providing a framework for development of legal norms dealing with this important issue. The third edition of the WHO guidelines also points out that if complementary environmental factors, leading to a substantial reduction of pathogen and indicator organism levels are taken into account, the degree of TC removal necessary to be monitored and validated the complexity and requirements of the waste water treatment process need not be more than 4 logs or 99.99% (Levi *et al.*, 2011).

FAO standards for treated waste water intended for agricultural

Where the WHO focuses mainly on microbiological quality parameters of treated waste water, the FAOs' guidelines for agricultural waste water quality standards, partly focusing on the physiochemical quality of treated waste water, include the single or combined application of measures to protect human health including waste water treatment, crop restriction, control of waste water application and human control & promotion of hygiene. The 1992 FAO guidelines rest on 3 pillars, trying to incorporate an integrated approach allowing for planning of waste water use in agriculture and will take advantage of the optimal combination of the health protection measures available granting for any soil & plant constraints in attaining an economic system suited to the local social cultural and institutional conditions. Since limitations in some administrative and legal systems, like the EU, pose a substantial barrier to the reliance of treated waste water as the only control mechanism aiming at the protection of human health connected to the application of treated waste water for agricultural purposes, irrigation systems should aim to be adequate in capacity of delivering low quality waste water and the number of crops irrigated in such a manner must become common practice in order to foster dialogue and technical cooperation on an international level (Pescod, 1992).

The first pillar of the WHO guidelines, human exposure control, is aiming to prevent respective groups of population at risk of direct contact with pathogens contained in irrigation water from direct exposure to these pathogens trying to avoid disease resulting from such hazards. Groups of people associated to high exposure risks of such contaminated irrigation water are agricultural workers and their families, crop handlers, consumers and the population living in the vicinity of areas irrigated with treated waste water. Provisions aiming at the protection of the health of the population group at risk include simple mitigation efforts such as the wearing of protective clothing, maintenance of high levels of hygiene and chemotherapeutic control of selected infections. Consumer risks are addressed by the recommendation of cooking the produce before consumption combined with high standards of food hygiene (Pescod, 1992). Furthermore, residents In the vicinity of agricultural areas irrigated by such methods should be kept fully informed about the irrigation system in place and all potential health risks associated to the human consumption of such contaminated water.

Table 7: Recommended microbiological quality guidelines for waste water use in agriculture

Category	Reuse condition	Exposed group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c]	Faecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parksd[d]	Workers, consumers, public	≤ 1	≤ 1000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and the guidelines modified accordingly.
[b] *Ascaris* and *Trichuris* species and hookworms.
[c] During the irrigation period.
[d] A more stringent guideline (<200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

source: WHO, 1989

Pillar number two, dealing with effluent quality for the protection of human health is based on the consensus view, between environmental specialists, epidemiologists and the WHO Scientific Group on Health Aspects of Use of Treated Waste Water for Agriculture and Aquaculture, that the actual risks associated to the irrigation with treated waste water is well below the levels than previously assumed in the 1989 and 1973 WHOs' published guidelines. In respect of the requirement to reduce the numbers of helminth eggs and protozoan cysts in effluents for Category A and B conditions to a level of not more than one per litre, the FAO's guidelines are more stringent than other standards. Albeit no maximum concentrations of bacterial pathogens are imposed for farm workers, Category C, and the absence of conclusive evidence of health risks from such bacteria, a reduction of bacterial contamination levels is recommended by the FAO. Effluent quality guidelines set out by the WHO in 1989 in respect to their reuse condition, exposure group and category, the design values for waste water treatment schemes are outlined in Table 7 above, where waste water treatment operations capable of producing the recommended microbiological quality consistently as a result of their intrinsic design parameters, rather than by high standards operational control, are to be preferred. Other than focusing solely on the protection of human health, all considerations related to groundwater contamination, soil structure and crop productivity must be scrutinised (Pescod, 1992).

Water quality guidelines for maximum crop production represent the FAOs' the third pillar in their hierarchy of addressing and mitigating risks related to the use of treated waste water in agriculture. Indicative water quality classifications reflecting on potential benefits and disadvantages to maximum crop production need to be applied cautiously since the condition under which treated waste water is used for irrigation vary in their extent, complexity and are hard to predict. The species of crop intended for cultivation, the climatic conditions, physical and chemical soil parameters and the salinity tolerance of the crop itself play an integral part in assessing the suitability of the treated waste water intended for use and can only be classified on a more general level reflecting average operation conditions. For determination of effects on the crop caused by pollutants contained in treated waste water, the classification scheme for irrigation water, established by Ayer and Westcot (FAO 1985), can be used, since these quality classification guidelines identify potential crop productions and yield reduction problems associated to the application of conventionally abstracted fresh water for irrigation. The Ayer Westcot classification scheme distinguishes between salinity, sodicity, toxicity and miscellaneous hazards as seen in Table 8 (Pescod, 1992).

Table 8: Guidelines for interpretation of water quality for irrigation after Ayer&Westcot

Potential irrigation problem		Units	Degree of restriction on use: None	Slight to moderate	Severe
Salinity					
Ec_w[1]		dS/m	< 0.7	0.7 - 3.0	> 3.0
or					
TDS		mg/l	< 450	450 - 2000	> 2000
Infiltration					
SAR[2] = 0 - 3 and EC_w			> 0.7	0.7 - 0.2	< 0.2
	03.Jun		> 1.2	1.2 - 0.3	< 0.3
	06.Dez		> 1.9	1.9 - 0.5	< 0.5
	Dez.20		> 2.9	2.9 - 1.3	< 1.3
	20-40		> 5.0	5.0 - 2.9	< 2.9
Specific ion toxicity					
Sodium (Na)					
	Surface irrigation	SAR	< 3	03.Sep	> 9
	Sprinkler irrigation	me/l	< 3	> 3	
Chloride (Cl)					
	Surface irrigation	me/l	< 4	04.Okt	> 10
	Sprinkler irrigation	m³/l	< 3	> 3	
Boron (B)		mg/l	< 0.7	0.7 - 3.0	> 3.0
Trace Elements					
(see other Table)					
Miscellaneous effects					
Nitrogen (NO_3-N)[3]		mg/l	< 5	Mai.30	> 30
Bicarbonate (HCO_3)		me/l	< 1.5	1.5 - 8.5	> 8.5
pH		Normal range 6.5-8			

[1] EC_w means electrical conductivity in deciSiemens per metre at 25°C

[2] SAR means sodium adsorption ratio

[3] NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen

source: FAO, 1985

Effluents from municipal waste water treatment may also contain various traces of toxic elements such as heavy metals, some of are removed during the waste water treatment processes but other tenacious contaminants are not discharged during the treatment process and could lead to phytotoxic issues. Sodium ions contained in the irrigation water and its effect on reducing the soil infiltration rate and soil permeability is condition to the SAR (Sodium Absorption Ratio), the sodium ion concentration relative to the concentration of calcium and magnesium ions, and the absolute salt concentration.

At a given SAR value, an increase in the overall salt concentration is expected to increase soil permeability and conversely an increase in SAR, for a given salt concentration, is likely to decrease soil permeability (Pescod, 1992). This leads to the conclusion that soil permeability, the infiltration rate and surface crusting hazards caused by sodium contained in irrigation water are very complex to predict on a general level and needs monitoring of the dissolved salt content in either the irrigation water or the soil layer. That's the reason why all crop water demand calculations conducted with the FAOs CropWat8.0 assumed uniform soil in all locations investigated. Secondary Stalinization and the increase of desertification in many irrigated areas of developed countries can be traced back to artificially elevated levels of salt & geochemical balances due to irrigation processes using treated waste water. The tendency of reducing soil fertility caused by the continuous increase of soil salinity, exclusively in regions with an associated risk of desertification (Banin and Fish, 1985), bearing all future impacts of climate change in mind, are another reason to be cautious about the salinity hazard, especially since many areas which are already subject to water scarcity and expanding desertification are relying on the application of treated waste water to sustain their food production.

Standards for treated waste water intended for agricultural use according to the ISO

The International Organisation for Standardisation (ISO) has recognised the importance of the use of treated waste water in agriculture as it is a smart and cost-effective option for recycling water. It furthermore helps lowering the environmental impact and provides a lifeline for many agricultural communities where fresh water is scarce or limited resource. Out of that mind-set the ISO published four of standards guiding the use of treated waste water for irrigation projects between 2015 and 2016. All 4 parts (ISO 16075-1 to ISO 16075-4) are currently under review and their aim is to provide specification for all elements of a project using treated waste water for irrigation, including design, materials, construction and performance of restricted & unrestricted irrigation of agricultural crops, irrigation of public urban green spaces (parks, sport fields and landscape areas) and the irrigation of private individual gardens. The audience these guidelines are intended to serve are largely with commercial background such as irrigation & water companies, agricultural extension officers & advisors as well as local authorities. Every part of the ISO standards ordains different stages in the development of a “reuse project for irrigation”, where part 1 outlines the basis of a reuse project for irrigation, part 2 is setting the steps for the development of the project, part 3 is addressing the components of a reuse project for irrigation and part for deals with monitoring. Part 2 is one of the most relevant in respect to this thesis since it deals with the quality of treated waste water than can be used for irrigation, the types of crops that can be irrigated with treated waste water, the strategy of using barriers than can reduce the risks arising from treated waste water irrigation, the correlation between the quality of treated waste water, the irrigated corps & the types of barriers that can be used and the distance between irrigation & residential areas. Part four is also important, especially because monitoring requirements, such as monitoring the quality of treated waste water or irrigation, monitoring of irrigated plants, mentoring of irrigated soil in regard to salinity, monitoring of natural water sources in neighbouring environments and monitoring the quality of water in storage reservoirs, outlined in these ISO standards go well above the FAO and WHO standards and include scrutiny of the immediate and neighbouring environment beyond the irrigation water, plant and soil level (ISO, 2017).

Summary on waste water related regulations

While FAO and WHO standards are primarily dealing with potential risks associated with human health, the environment and soil stability, the ISO requirements are focusing on all technical aspects regarding the regulation of utilizing treated waste water for irrigation in agriculture. The rules and guidelines set out by the Food and Agriculture Organisation of the United Nations and the World Health Organisation are, from a synoptic point of view, setting the same requirements in terms of protection against pathogens and other potential health hazards contained in urban waste water. These statutes were agreed on an international level more than a generation ago and are currently under review since many technological advances, scientific progress and empiric data clearly indicate that a thorough update is required. Although these regulations are of historic relevance, and still highly important on an international policy making level, national rules and regulations, especially in Australia and the United Stated of America, follow a more sensible path. Australian and Californian legislation follows a type specific approach, where permissive contamination levels, and the entailed water treatment costs, are dependent on the type of crop irrigated, the technological barriers installed, the type of produce, the way the produce is consumed and the expected effects impacting human health and environmental integrity. Where such national legislation already provides a sophisticated and elaborated framework, the superordinate standards set out by the International Organisations allow for conducting a legitimate risk assessment.

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Annex 1: Results

Northern Europe	Winners			Livestock	Winners	
1	Wheat	3.859.242	ha/a	Chicken	139	l/a/head
2	Barley	3.767.972	ha/a	Sheep	2.613	l/a/head
3	Oats	1.023.430	ha/a	Pig	3.346	l/a/head
population		97.445.116	people			
prod mun WW		700.333.333	m3/a			
Treated mun ww		436.000.000	m3/a			

Northern Europe	Wheat planting date	[mm] actual irrigation requirement	Barley planting date	[mm] actual irrigation requirement	Oats planting date	[mm] actual irrigation requirement
Denmark	1.3.	104,8	1.3.	95,8		n/a - cropwat
Ireland	1.3.	44,4	1.3.	35,6		n/a - cropwat
Sweden	1.3.	85,8	1.3.	77,9		n/a - cropwat
United Kingdom	1.3.	162,7	1.3.	154,3		n/a - cropwat
total		99,4		90,9		

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	3.837.372.962,00	Barley	3.425.400.545,67	Oats	0,00	7.262.773.507,67

waste water potential	Northern Europe	
crop irrigation	0,06	
livestock	0,04	
total	0,02	

Northern Europe		
Wheat		
harvested area	3.859.242,00	[ha]
cropwat result (avg. mm irr. demand)	99,43	[mm / a] | [l/m² / a]
	994.333,33	[l/ha / a]
	994,33	[m³/ha / a]
Wheat	3.837.372.962,00	[m³/a]
tot irr dem for 3 main crops / a	7.262.773.507,67	[m³/a]
treated ww in region	436.000.000,00	[m³/a]
	11,36	% ww of irr. demand from ww
ha crops irr. with treated ww	438.484,75	[ha]
Wheat	364,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]
	0,0000878	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]
	10,35	[p/ha]
	0,10	[ha/p]
which crop is most suitable to feed humanity		
Wheat	96,10	[m³ irr. water /p / a]
Northern Europe		
pop. pot.fed with treated ww	4.536.815,47	[p]
	4,66	% of people pot. fed
which animal is most suitable to feed humanity		
all animals fed with	**Wheat**	
	Chicken	
meat	4.459,84	[kcal/head]
	245,52	[heads /p / a]
	0,139	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]
	3,91	[m³ irr. water/head animal food]
	4,053	[m³/head total]
	995,04	[m³ irr, water / p / a]
	210.277.516,00	[head/a]
	29.133.511,76	[m³ feed water / a]
	852.197.066,07	[m³ irrigation water / a]
	881.330.577,84	[m³ water demand livestock total / a]

Northern Europe		
Barley		
	3.767.972,00	[ha]
	90,91	[mm / a] | [l/m² / a]
	909.083,33	[l/ha / a]
	909,08	[m³/ha / a]
Barley	3.425.400.545,67	[m³/a]
	7.262.773.507,67	[m³/a]
	436.000.000,00	[m³/a]
	12,73	% ww of irr. demand from ww
	479.604,00	[ha]
Barley	345,00	[kcal / 100g]
	3.450.000,00	[kcal/ton]
	8.006.156,25	[kcal/ha]
	0,0001135	[m³ irr. / kcal]
		[kcal/p/a]
	7,31	[p/ha]
	0,14	[ha/p]
which crop is most suitable to feed humanity		
Barley	124,34	[m³ irr. water /p / a]
	3.506.652,54	[p]
	3,60	% of people pot. fed
which animal is most suitable to feed humanity		
	Sheep	
	178.568,73	[kcal/head]
	6,13	[heads /p / a]
	2,613	[m³/head animal feed water / a]
	1.785.687,30	[kcal food for 1 head]
	156,72	[m³ irr. water/head animal food]
	159,334	[m³/head total]
	977,05	[m³ irr, water / p / a]
	47.470.945,00	[head/a]
	124.060.567,66	[m³ feed water / a]
	7.563.745.470,95	[m³ irrigation water / a]
	7.687.806.038,61	[m³ water demand livestock total / a]

Northern Europe			
Oats			
	1.023.430,00	[ha]	
	-	[mm / a] | [l/m² / a]	
	-	[l/ha / a]	
	-	[m³/ha / a]	
Oats	0,00	[m³/a]	
	7.262.773.507,67	[m³/a]	
	436.000.000,00	[m³/a]	
	#DIV/0!	% ww of irr. demand from ww	
	#DIV/0!	[ha]	
Oats	404,00	[kcal / 100g]	
	4.040.000,00	[kcal/ton]	
	14.746.000,00	[kcal/ha]	
	-	[m³ irr. / kcal]	
		[kcal/p/a]	
	13,47	[p/ha]	
	0,07	[ha/p]	
which crop is most suitable to feed humanity			
Oats	-	[m³ irr. water /p / a]	
	#DIV/0!	[p]	
	#DIV/0!	% of people pot. fed	
which animal is most suitable to feed humanity			
	Pig		
	83.765,50	[kcal/head]	
	13,07	[heads /p / a]	
	3,346	[m³/head animal feed water / a]	
	837.655,00	[kcal food for 1 head]	
	73,52	[m³ irr. water/head animal food]	
	76,863	[m³/head total]	
	1.004,76	[m³ irr, water / p / a]	
	25.018.375,00	[head/a]	
	83.707.313,02	[m³ feed water / a]	
	1.922.977.527,78	[m³ irrigation water / a]	total m3 / a
	2.006.684.840,80	[m³ water demand livestock total / a]	10.575.821.457,25

Eastern Europe		Winners		Livestock	Winners	
1	Wheat	40.940.286	ha/a	Chicken	139	l/a/head
2	Barley	19.535.703	ha/a	Pig	3.346	l/a/head
3	Maize	8.742.981	ha/a	Cattle	14.418	l/a/head
population		279.610.389	people			
prod mun WW		1.156.755.000	m3/a			
Treated mun ww		606.000.000	m3/a			

Eastern Europe	Wheat planting date	[mm] actual irrigation requirement	Barley planting date	[mm] actual irrigation requirement	Maize planting date	[mm] actual irrigation requirement
Bulgaria	1.3.	260,8	1.3.	113,5	1.3.	135,4
Czechia	1.3.	118,3	1.3.	118,6	1.3.	135,8
Poland	1.3.	90,6	1.3.	90,0	1.3.	104,3
Russian Federation	1.4.	34,8	1.4.	31,5	1.4.	47,0
total		126,1		88,4		105,6

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	51.630.818.181,75	Barley	17.267.119.489,13	Maize	9.233.680.808,63	78.131.618.479,50

waste water potential	Eastern Europe	
crop irrigation	0,01	
livestock	0,01	
total	0,00	

Eastern Europe			*Eastern Europe*		
Wheat			**Barley**		
harvested area	40.940.286,00	[ha]		19.535.703,00	[ha]
cropwat result (avg. mm irr.	126,11	[mm / a] | [l/m² / a]		88,39	[mm / a] | [l/m² / a]
	1.261.125,00	[l/ha / a]		883.875,00	[l/ha / a]
	1.261,13	[m³/ha / a]		883,88	[m³/ha / a]
Wheat	51.630.818.181,75	[m³/a]	**Barley**	17.267.119.489,13	[m³/a]
tot irr dem for 3 main crops	78.131.618.479,50	[m³/a]		78.131.618.479,50	[m³/a]
treated ww in region	606.000.000,00	[m³/a]		606.000.000,00	[m³/a]
	1,17	% ww of irr. demand from ww		3,51	% ww of irr. demand from ww
ha crops irr. with treated ww	480.523,34	[ha]		685.617,31	[ha]
Wheat	364,00	[kcal / 100g]	Barley	345,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.450.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]		8.006.156,25	[kcal/ha]
	0,0001113	[m³ irr. / kcal]		0,0001104	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,35	[p/ha]		7,31	[p/ha]
	0,10	[ha/p]		0,14	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Wheat	121,89	[m³ irr. water /p / a]	Barley	120,89	[m³ irr. water /p / a]
pop. pot.fed with treated w	4.971.770,96	[p]		5.012.930,88	[p]
	1,78	% of people pot. fed		1,79	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Wheat**				
	Chicken			**Pig**	
meat	4.459,84	[kcal/head]		83.765,50	[kcal/head]
	245,52	[heads /p / a]		13,07	[heads /p / a]
	0,139	[m³/head animal feed water / a]		3,346	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		837.655,00	[kcal food for 1 head]
	4,96	[m³ irr. water/head animal food]		93,24	[m³ irr. water/head animal food]
	5,103	[m³/head total]		96,588	[m³/head total]
	1.252,90	[m³ irr, water / p / a]		1.262,62	[m³ irr, water / p / a]
	977.172.484,00	[head/a]		76.215.906,00	[head/a]
	135.385.211,88	[m³ feed water / a]		255.005.718,83	[m³ feed water / a]
	4.986.459.204,70	[m³ irrigation water / a]		7.361.545.525,26	[m³ irrigation water / a]
	5.121.844.416,58	[m³ water demand livestock total / a]		7.616.551.244,09	[m³ water demand livestock total / a]

Eastern Europe		
Maize		
	8.742.981,00	[ha]
	105,61	[mm / a] | [l/m² / a]
	1.056.125,00	[l/ha / a]
	1.056,13	[m³/ha / a]
Maize	9.233.680.808,63	[m³/a]
	78.131.618.479,50	[m³/a]
	606.000.000,00	[m³/a]
	6,56	% ww of irr. demand from ww
	573.795,72	[ha]
Maize	363,50	[kcal / 100g]
	3.635.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]
	0,0000777	[m³ irr. / kcal]
		[kcal/p/a]
	12,41	[p/ha]
	0,08	[ha/p]
which crop is most suitable to feed humanity		
Maize	85,09	[m³ irr. water /p / a]
Eastern Europe		
	7.121.541,72	[p]
	2,55	% of people pot. fed
which animal is most suitable to feed humanity		
	Cattle	
	847.973,25	[kcal/head]
	1,29	[heads /p / a]
	14,418	[m³/head animal feed water / a]
	8.479.732,50	[kcal food for 1 head]
	943,91	[m³ irr. water/head animal food]
	958,325	[m³/head total]
	1.237,50	[m³ irr, water / p / a]
	70.030.918,00	[head/a]
	1.009.670.760,27	[m³ feed water / a]
	67.112.395.735,62	[m³ irrigation water / a]
	68.122.066.495,88	[m³ water demand livestock total / a]

total m3 / a
80.860.462.156,55

Southern Europe		Winners			Livestock	Winners	
1	Wheat		6.577.212	ha/a	Chicken	139	l/a/head
2	Barley		4.115.813	ha/a	Sheep	2.613	l/a/head
3	Maize		3.650.043	ha/a	Pig	3.346	l/a/head
population			139.154.354	people			
prod mun WW			650.325.694	m3/a			
Treated mun ww			563.000.000	m3/a			

Southern Europe	Wheat planting date	[mm] actual irrigation requirement	Barley planting date	[mm] actual irrigation requirement	Maize planting date	[mm] actual irrigation requirement
Greece	1.3.	172,8	1.3.	230,75	1.3.	268,4
Italy	1.3.	50,2	1.3.	26,1	1.3.	48,5
Portugal	1.3.	159,6	1.3.	121,1	1.3.	157,2
Serbia	1.3.	19,6	1.3.	5,7	1.3.	22,5
Spain	1.3.	251,3	1.3.	228,4	1.3.	255,8
total		130,7		122,4		150,5

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	8.595.758.362,80	Barley	5.038.166.693,30	Maize	5.492.584.706,40	19.126.509.762,50

waste water potential	Southern Europe	
crop irrigation	0,03	
livestock	0,03	
total	0,02	

Southern Europe			*Southern Europe*		
Wheat			**Barley**		
harvested area	6.577.212,00	[ha]		4.115.813,00	[ha]
cropwat result (avg. mm irr. demand)	130,69	[mm / a] | [l/m^2 / a]		122,41	[mm / a] | [l/m^2 / a]
	1.306.900,00	[l/ha / a]		1.224.100,00	[l/ha / a]
	1.306,90	[m^3/ha / a]		1.224,10	[m^3/ha / a]
Wheat	8.595.758.362,80	[m^3/a]	**Barley**	5.038.166.693,30	[m^3/a]
tot irr dem for 3 main crops / a	19.126.509.762,50	[m^3/a]		19.126.509.762,50	[m^3/a]
treated ww in region	563.000.000,00	[m^3/a]		563.000.000,00	[m^3/a]
	6,55	% ww of irr. demand from ww		11,17	% ww of irr. demand from ww
ha crops irr. with treated ww	430.790,42	[ha]		459.929,74	[ha]
Wheat	364,00	[kcal / 100g]	Barley	345,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.450.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]		8.006.156,25	[kcal/ha]
	0,0001154	[m^3 irr. / kcal]		0,0001529	[m^3 irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,35	[p/ha]		7,31	[p/ha]
	0,10	[ha/p]		0,14	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Wheat	126,31	[m^3 irr. water / p / a]	Barley	167,42	[m^3 irr. water / p / a]
pop. pot.fed with treated ww	4.457.205,54	[p]		3.362.803,10	[p]
	3,20	% of people pot. fed		2,42	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Wheat**				
	Chicken			**Sheep**	
meat	4.459,84	[kcal/head]		178.568,73	[kcal/head]
	245,52	[heads / p / a]		6,13	[heads / p / a]
	0,139	[m^3/head animal feed water / a]		2,613	[m^3/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		1.785.687,30	[kcal food for 1 head]
	5,14	[m^3 irr. water/head animal food]		205,99	[m^3 irr. water/head animal food]
	5,283	[m^3/head total]		208,599	[m^3/head total]
	1.297,14	[m^3 irr, water / p / a]		1.279,15	[m^3 irr, water / p / a]
	347.190.161,00	[head/a]		49.205.844,00	[head/a]
	48.102.473,49	[m^3 feed water / a]		128.594.552,71	[m^3 feed water / a]
	1.834.254.011,20	[m^3 irrigation water / a]		10.264.293.662,25	[m^3 irrigation water / a]
	1.882.356.484,69	[m^3 water demand livestock total / a]		10.392.888.214,96	[m^3 water demand livestock total / a]

	Southern Europe		
Maize			
	3.650.043,00	[ha]	
	150,48	[mm / a] | [l/m² / a]	
	1.504.800,00	[l/ha / a]	
	1.504,80	[m³/ha / a]	
Maize	5.492.584.706,40	[m³/a]	
	19.126.509.762,50	[m³/a]	
	563.000.000,00	[m³/a]	
	10,25	% ww of irr. demand from ww	
	374.136,10	[ha]	
Maize	363,50	[kcal / 100g]	
	3.635.000,00	[kcal/ton]	
	13.590.356,25	[kcal/ha]	
	0,0001107	[m³ irr. / kcal]	
		[kcal/p/a]	
	12,41	[p/ha]	
	0,08	[ha/p]	
	which crop is most suitable to feed humanity		
Maize Southern Europe	121,24	[m³ irr. water /p / a]	
	4.643.509,46	[p]	
	3,34	% of people pot. fed	
	which animal is most suitable to feed humanity		
	Pig		
	83.765,50	[kcal/head]	
	13,07	[heads /p / a]	
	3,346	[m³/head animal feed water / a]	
	837.655,00	[kcal food for 1 head]	
	96,63	[m³ irr. water/head animal food]	
	99,972	[m³/head total]	
	1.306,86	[m³ irr, water / p / a]	
	40.871.055,00	[head/a]	
	136.747.738,19	[m³ feed water / a]	
	4.085.979.740,44	[m³ irrigation water / a]	total m3 / a
	4.222.727.478,63	[m³ water demand livestock total / a]	16.497.972.178,27

Western Europe		Winners		Livestock	Winners	
1	Wheat	8.751.162	ha/a	Chicken	139	l/a/head
2	Barley	4.107.841	ha/a	Pig	2.613	l/a/head
3	Maize	2.377.924	ha/a	Cattle	14.418	l/a/head
population		179.862.430	people			
prod mun WW		2.100.727.778	m3/a			
Treated mun ww		2.202.340.000	m3/a			

Western Europe	Wheat planting date	[mm] actual irrigation requirement	Barley planting date	[mm] actual irrigation requirement	Maize planting date	[mm] actual irrigation requirement
Austria	1.3.	54,7	1.3.	57,4	1.3.	63,5
Belgium	1.3.	26,9	1.3.	20,0	1.3.	35,2
France	1.3.	109,7	1.3.	98,1	1.3.	118,6
Germany	1.3.	68,6	1.3.	66,3	1.3.	81,0
Netherlands	1.3.	51,4	1.3.	45,7	1.3.	60,2
total		62,3		57,5		71,7

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	5.448.473.461,20	Barley	2.362.008.575,00	Maize	1.704.971.508,00	9.515.453.544,20

waste water potential	Western Europe	
crop irrigation	0,23	
livestock	0,08	
total	0,06	

Western Europe			*Western Europe*		
Wheat			**Barley**		
harvested area	8.751.162,00	[ha]		4.107.841,00	[ha]
cropwat result (avg. mm irr. demand)	62,26	[mm / a] | [l/m² / a]		57,50	[mm / a] | [l/m² / a]
	622.600,00	[l/ha / a]		575.000,00	[l/ha / a]
	622,60	[m³/ha / a]		575,00	[m³/ha / a]
Wheat	5.448.473.461,20	[m³/a]	**Barley**	2.362.008.575,00	[m³/a]
tot irr dem for 3 main crops / a	9.515.453.544,20	[m³/a]		9.515.453.544,20	[m³/a]
treated ww in region	2.202.340.000,00	[m³/a]		2.202.340.000,00	[m³/a]
	40,42	% ww of irr. demand from ww		93,24	% ww of irr. demand from ww
ha crops irr. with treated ww	3.537.327,34	[ha]		3.830.156,52	[ha]
Wheat	364,00	[kcal / 100g]	Barley	345,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.450.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]		8.006.156,25	[kcal/ha]
	0,0000550	[m³ irr. / kcal]		0,0000718	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,35	[p/ha]		7,31	[p/ha]
	0,10	[ha/p]		0,14	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Wheat	60,17	[m³ irr. water /p / a]	Barley	78,64	[m³ irr. water /p / a]
pop. pot.fed with treated ww	36.599.223,80	[p]		28.004.412,40	[p]
	20,35	% of people pot. fed		15,57	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Wheat**				
	Chicken			**Pig**	
meat	4.459,84	[kcal/head]		83.765,50	[kcal/head]
	245,52	[heads /p / a]		13,07	[heads /p / a]
	0,139	[m³/head animal feed water / a]		2,613	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		837.655,00	[kcal food for 1 head]
	2,45	[m³ irr. water/head animal food]		46,03	[m³ irr. water/head animal food]
	2,589	[m³/head total]		48,646	[m³/head total]
	635,76	[m³ irr, water / p / a]		635,91	[m³ irr, water / p / a]
	479.299.323,00	[head/a]		66.017.874,00	[head/a]
	66.405.922,66	[m³ feed water / a]		172.531.111,91	[m³ feed water / a]
	1.241.099.154,51	[m³ irrigation water / a]		3.211.491.870,82	[m³ irrigation water / a]
	1.307.505.077,18	[m³ water demand livestock total / a]		3.384.022.982,73	[m³ water demand livestock total / a]

Western Europe			
Maize			
	2.377.924,00	[ha]	
	71,70	[mm / a] | [l/m² / a]	
	717.000,00	[l/ha / a]	
	717,00	[m³/ha / a]	
Maize	1.704.971.508,00	[m³/a]	
	9.515.453.544,20	[m³/a]	
	2.202.340.000,00	[m³/a]	
	129,17	% ww of irr. demand from ww	
	3.071.603,91	[ha]	
Maize	363,50	[kcal / 100g]	
	3.635.000,00	[kcal/ton]	
	13.590.356,25	[kcal/ha]	
	0,0000528	[m³ irr. / kcal]	
		[kcal/p/a]	
	12,41	[p/ha]	
	0,08	[ha/p]	
which crop is most suitable to feed humanity			
Maize Western Europe	57,77	[m³ irr. water /p / a]	
	38.122.549,16	[p]	
	21,20	% of people pot. fed	
which animal is most suitable to feed humanity			
	Cattle		
	847.973,25	[kcal/head]	
	1,29	[heads /p / a]	
	14,418	[m³/head animal feed water / a]	
	8.479.732,50	[kcal food for 1 head]	
	465,99	[m³ irr. water/head animal food]	
	480,412	[m³/head total]	
	620,36	[m³ irr, water / p / a]	
	46.260.656,00	[head/a]	
	666.963.007,88	[m³ feed water / a]	
	22.224.161.068,25	[m³ irrigation water / a]	total m3 / a
	22.891.124.076,13	[m³ water demand livestock total / a]	27.582.652.136,04

Northern Africa		Winners		Livestock	Winners	
1	Wheat	6.666.707	ha/a	Chicken	139	l/a/head
2	Sorghum	6.013.715	ha/a	Sheep	2.613	l/a/head
3	Barley	3.634.853	ha/a	Goat	3.699	l/a/head
Population		184.119.907	people			
prod mun WW		1.379.936.667	m3/a			
Treated mun ww		580.540.000	m3/a			

Northern Africa	Wheat planting date	[mm] actual irrigation requirement	Sorghum planting date	[mm] actual irrigation requirement	Barley planting date	[mm] actual irrigation requirement
Egypt	1.4.	780,8	1.4.	737,6	1.4.	808,1
Sudan	1.4.	630,3	1.4.	602,5	1.4.	712,6
Tunisia	1.4.	545,6	1.4.	505,9	1.4.	540,3
total		652,2		615,3		687,0

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	43.482.485.289,67	Sorghum	37.004.392.966,67	Barley	24.971.440.110,00	105.458.318.366,33

waste water potential	Northern Africa	
crop irrigation	0,01	
livestock	0,00	
total	0,00	

Northern Africa			*Northern Africa*		
Wheat			**Sorghum**		
harvested area	6.666.707,00	[ha]		6.013.715,00	[ha]
cropwat result (avg. mm irr. demand)	652,23	[mm / a] | [l/m² / a]		615,33	[mm / a] | [l/m² / a]
	6.522.333,33	[l/ha / a]		6.153.333,33	[l/ha / a]
	6.522,33	[m³/ha / a]		6.153,33	[m³/ha / a]
Wheat	43.482.485.289,67	[m³/a]	**Sorghum**	37.004.392.966,67	[m³/a]
tot irr dem for 3 main crops / a	105.458.318.366,33	[m³/a]		3.776.522.167,33	[m³/a]
treated ww in region	580.540.000,33	[m³/a]		580.540.000,33	[m³/a]
	1,34	% ww of irr. demand from ww		1,57	% ww of irr. demand from ww
ha crops irr. with treated ww	89.008,02	[ha]		94.345,61	[ha]
Wheat	364,00	[kcal / 100g]	Sorghum	359,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.590.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]		4.895.563,33	[kcal/ha]
	0,0005757	[m³ irr. / kcal]		0,0012569	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,35	[p/ha]		4,47	[p/ha]
	0,10	[ha/p]		0,22	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Wheat	630,39	[m³ irr. water /p / a]	Sorghum	1.376,33	[m³ irr. water / p / a]
Northern Africa					
pop. pot.fed with treated ww	920.928,22	[p]		421.803,58	[p]
	0,50	% of people pot. fed		0,23	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Wheat**				
	Chicken			**Sheep**	
meat	4.459,84	[kcal/head]		178.568,73	[kcal/head]
	245,52	[heads /p / a]		6,13	[heads /p / a]
	0,139	[m³/head animal feed water / a]		2,613	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		1.785.687,30	[kcal food for 1 head]
	25,68	[m³ irr. water/head animal food]		1.028,01	[m³ irr. water/head animal food]
	25,814	[m³/head total]		1.030,624	[m³/head total]
	6.337,87	[m³ irr, water / p / a]		6.319,88	[m³ irr, water / p / a]
	449.496.742,00	[head/a]		93.550.691,00	[head/a]
	62.276.837,15	[m³ feed water / a]		244.485.375,86	[m³ feed water / a]
	11.603.134.191,77	[m³ irrigation water / a]		96.415.601.456,34	[m³ irrigation water / a]
	11.665.411.028,92	[m³ water demand livestock total / a]		96.660.086.832,20	[m³ water demand livestock total / a]

Northern Africa			
Barley			
	3.634.853,00	[ha]	
	687,00	[mm / a] | [l/m² / a]	
	6.870.000,00	[l/ha / a]	
	6.870,00	[m³/ha / a]	
Barley	24.971.440.110,00	[m³/a]	
	3.776.522.167,33	[m³/a]	
	580.540.000,33	[m³/a]	
	2,32	% ww of irr. demand from ww	
	84.503,64	[ha]	
Barley	345,00	[kcal / 100g]	
	3.450.000,00	[kcal/ton]	
	8.006.156,25	[kcal/ha]	
	0,0008581	[m³ irr. / kcal]	
		[kcal/p/a]	
	7,31	[p/ha]	
	0,14	[ha/p]	
which crop is most suitable to feed humanity			
Barley	939,61	[m³ irr. water /p / a]	
	617.853,28	[p]	
	0,34	% of people pot. fed	
which animal is most suitable to feed humanity			
	Goat		
	75.000,00	[kcal/head]	
	14,60	[heads /p / a]	
	3,699	[m³/head animal feed water / a]	
	750.000,00	[kcal food for 1 head]	
	431,77	[m³ irr. water/head animal food]	
	435,470	[m³/head total]	
	6.357,86	[m³ irr, water / p / a]	
	48.405.466,00	[head/a]	
	179.035.683,58	[m³ feed water / a]	
	21.079.114.090,00	[m³ irrigation water / a]	total m3 / a
	21.258.149.773,57	[m³ water demand livestock total / a]	129.583.647.634,69

Middle Africa		Crops	Winners		Livestock	Winners	
	1	Maize	3.554.603	ha/a	Chicken	139	l/a/head
	2	Sorghum	1.483.400	ha/a	Goats	3.699	l/a/head
	3	Millet	1.156.366	ha/a	Cattle	14.418	l/a/head
Population			138.448.919	people			
prod mun WW			66.200.000	m3/a			
Treated mun ww			3.050.000	m3/a			

Middle Africa	Maize planting date	[mm] actual irrigation requirement	Sorghum planting date	[mm] actual irrigation requirement	Millet planting date	[mm] actual irrigation requirement
Cameroon	1.5.	14,2	1.5.	10,7	1.5.	0,6
Congo	1.5.	163,7	1.5.	127,2	1.5.	101,7
Democratic Republic of the Congo	1.5.	40,3	1.5.	12,1	1.5.	14,3
total		72,7		50,0		38,9

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Maize	2.585.381.248,67	Sorghum	741.700.000,00	Millet	449.440.918,67	3.776.522.167,33

waste water potential	Middle Africa	
crop irrigation	0,00	
livestock	0,00	
total	0,00	

Middle Africa			*Middle Africa*		
Maize			**Sorghum**		
harvested area	3.554.603,00	[ha]		1.483.400,00	[ha]
cropwat result (avg. mm irr. demand)	72,73	[mm / a] | [l/m² / a]		50,00	[mm / a] | [l/m² / a]
	727.333,33	[l/ha / a]		500.000,00	[l/ha / a]
	727,33	[m³/ha / a]		500,00	[m³/ha / a]
Maize	2.585.381.248,67	[m³/a]	**Sorghum**	741.700.000,00	[m³/a]
tot irr dem for 3 main crops / a	3.776.522.167,33	[m³/a]		3.776.522.167,33	[m³/a]
treated ww in region	3.050.000,00	[m³/a]		3.050.000,00	[m³/a]
	0,12	% ww of irr. demand from ww		0,41	% ww of irr. demand from ww
ha crops irr. with treated ww	4.193,40	[ha]		6.100,00	[ha]
Maize	363,50	[kcal / 100g]	Sorghum	359,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.590.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]		4.895.563,33	[kcal/ha]
	0,0000535	[m³ irr. / kcal]		0,0001021	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	12,41	[p/ha]		4,47	[p/ha]
	0,08	[ha/p]		0,22	[ha/p]
which crop is most suitable to feed humanity			***which crop is most suitable to feed humanity***		
Maize	58,60	[m³ irr. water /p / a]	Sorghum	111,84	[m³ irr. water /p / a]
Middle Africa					
pop. pot.fed with treated ww	52.045,49	[p]		27.272,09	[p]
	0,04	% of people pot. fed		0,02	% of people pot. fed
which animal is most suitable to feed humanity			***which animal is most suitable to feed humanity***		
all animals fed with	**Maize**				
	Chicken			**Goats**	
meat	4.459,84	[kcal/head]		75.000,00	[kcal/head]
	245,52	[heads /p / a]		14,60	[heads /p / a]
	0,139	[m³/head animal feed water / a]		3,699	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		750.000,00	[kcal food for 1 head]
	2,39	[m³ irr. water/head animal food]		40,14	[m³ irr. water/head animal food]
	2,525	[m³/head total]		43,837	[m³/head total]
	620,04	[m³ irr, water / p / a]		640,03	[m³ irr, water / p / a]
	82.722.161,00	[head/a]		22.457.293,00	[head/a]
	11.460.983,07	[m³ feed water / a]		83.062.041,04	[m³ feed water / a]
	208.904.919,02	[m³ irrigation water / a]		984.469.855,98	[m³ irrigation water / a]
	220.365.902,09	[m³ water demand livestock total / a]		1.067.531.897,02	[m³ water demand livestock total / a]

Middle Africa			
Millet			
	1.156.366,00	[ha]	
	38,87	[mm / a] | [l/m² / a]	
	388.666,67	[l/ha / a]	
	388,67	[m³/ha / a]	
Millet	449.440.918,67	[m³/a]	
	3.776.522.167,33	[m³/a]	
	3.050.000,00	[m³/a]	
	0,68	% ww of irr. demand from ww	
	7.847,34	[ha]	
Millet	378,00	[kcal / 100g]	
	3.780.000,00	[kcal/ton]	
	2.835.000,00	[kcal/ha]	
	0,0001371	[m³ irr. / kcal]	
		[kcal/p/a]	
	2,59	[p/ha]	
	0,39	[ha/p]	
which crop is most suitable to feed humanity			
Millet	150,12	[m³ irr. water /p / a]	
	20.317,09	[p]	
	0,01	% of people pot. fed	
which animal is most suitable to feed humanity			
	Cattle		
	847.973,25	[kcal/head]	
	1,29	[heads/p / a]	
	14,418	[m³/head animal feed water / a]	
	8.479.732,50	[kcal food for 1 head]	
	453,82	[m³ irr. water/head animal food]	
	468,239	[m³/head total]	
	604,64	[m³ irr, water / p / a]	
	21.632.569,00	[head/a]	
	311.887.563,56	[m³ feed water / a]	
	10.129.206.500,67	[m³ irrigation water / a]	total m3 / a
	10.441.094.064,23	[m³ water demand livestock total / a]	11.728.991.863,34

Eastern Africa		Winners		Livestock	Winners	
1	Maize	1.225.997	ha/a	Chicken	139	l/a/head
2	Sorghum	3.915.915	ha/a	Cattle	14.418	l/a/head
3	Rice, paddy	2.217.014	ha/a	Goats	3.699	l/a/head

Population	345.936.808	people
prod mun WW	41.450.000	m3/a
Treated mun ww	32.150.000	m3/a

Eastern Africa	Maize planting date	[mm] actual irrigation requirement	Sorghum planting date	[mm] actual irrigation requirement	Rice, paddy planting date	[mm] actual irrigation requirement
Burundi	1.4.	317,5	1.4.	277,1	1.5.	393,9
Ethiopia	1.4.	299,7	1.4.	239,9	1.5.	369,0
Kenya	1.4.	504,0	1.4.	444,1	1.5.	668,9
Madagascar	1.10.	152,2	1.10.	213,7	1.10.	42,2
Malawi	1.10.	118,1	1.10.	235,0	1.10.	154,3
Somalia	1.3.	514,6	1.3.	452,5	1.5.	733,6
Uganda	1.5.	131,6	1.5.	94,2	1.5.	1,2
Zambia	1.5.	493,0	1.5.	447,5	1.10.	222,4
Zimbabwe	1.5.	401,1	1.5.	363,3	1.10.	301,1
total		325,8		307,5		320,7

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Maize	3.993.753.338,44	Sorghum	12.040.568.421,67	Rice, paddy	7.110.702.902,67	23.145.024.662,78

waste water potential	Eastern Africa	
crop irrigation	0,00	
livestock	0,00	
total	0,00	

Eastern Africa			*Eastern Africa*		
Maize			**Sorghum**		
harvested area	1.225.997,00	[ha]		3.915.915,00	[ha]
cropwat result (avg. mm irr. demand)	325,76	[mm / a] | [l/m^2 / a]		307,48	[mm / a] | [l/m^2 / a]
	3.257.555,56	[l/ha / a]		3.074.777,78	[l/ha / a]
	3.257,56	[m^3/ha / a]		3.074,78	[m^3/ha / a]
Maize	3.993.753.338,44	[m^3/a]	**Sorghum**	12.040.568.421,67	[m^3/a]
tot irr dem for 3 main crops / a	23.145.024.662,78	[m^3/a]		3.776.522.167,33	[m^3/a]
treated ww in region	32.150.000,00	[m^3/a]		32.150.000,00	[m^3/a]
	0,81	% ww of irr. demand from ww		0,27	% ww of irr. demand from ww
ha crops irr. with treated ww	9.869,36	[ha]		10.456,04	[ha]
Maize	363,50	[kcal / 100g]	Sorghum	359,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.590.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]		4.895.563,33	[kcal/ha]
	0,0002397	[m^3 irr. / kcal]		0,0006281	[m^3 irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	12,41	[p/ha]		4,47	[p/ha]
	0,08	[ha/p]		0,22	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Maize	262,47	[m^3 irr. water /p / a]	Sorghum	687,74	[m^3 irr. water /p / a]
Eastern Africa					
pop. pot.fed with treated ww	122.491,48	[p]		46.747,22	[p]
	0,04	% of people pot. fed		0,01	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Maize**				
	Chicken			**Cattle**	
meat	4.459,84	[kcal/head]		847.973,25	[kcal/head]
	245,52	[heads /p / a]		1,29	[heads /p / a]
	0,14	[m^3/head animal feed water / a]		14,42	[m^3/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		8.479.732,50	[kcal food for 1 head]
	10,69	[m^3 irr. water/head animal food]		2.032,56	[m^3 irr. water/head animal food]
	10,829	[m^3/head total]		2.046,976	[m^3/head total]
	2.658,69	[m^3 irr, water / p / a]		2.643,29	[m^3 irr, water / p / a]
	269.453.935,00	[head/a]		112.044.093,00	[head/a]
	37.332.281,33	[m^3 feed water / a]		1.615.395.710,83	[m^3 feed water / a]
	2.917.811.845,55	[m^3 irrigation water / a]		229.351.615.489,84	[m^3 irrigation water / a]
	2.955.144.126,89	[m^3 water demand livestock total / a]		230.967.011.200,66	[m^3 water demand livestock total / a]

Eastern Africa			
Rice, paddy			
	2.217.014,00	[ha]	
	320,73	[mm / a] | [l/m² / a]	
	3.207.333,33	[l/ha / a]	
	3.207,33	[m³/ha / a]	
Rice, paddy	7.110.702.902,67	[m³/a]	
	3.776.522.167,33	[m³/a]	
	32.150.000,00	[m³/a]	
	0,45	% ww of irr. demand from ww	
	10.023,90	[ha]	
Rice, paddy	364,00	[kcal / 100g]	
	3.640.000,00	[kcal/ton]	
	11.963.466,67	[kcal/ha]	
	0,0002681	[m³ irr. / kcal]	
		[kcal/p/a]	
	10,93	[p/ha]	
	0,09	[ha/p]	
which crop is most suitable to feed humanity			
Rice, paddy	293,56	[m³ irr. water /p / a]	
	109.516,56	[p]	
	0,03	% of people pot. fed	
which animal is most suitable to feed humanity			
	Goats		
	75.000,00	[kcal/head]	
	14,60	[heads /p / a]	
	3,70	[m³/head animal feed water / a]	
	750.000,00	[kcal food for 1 head]	
	179,77	[m³ irr. water/head animal food]	
	183,471	[m³/head total]	
	2.678,67	[m³ irr, water / p / a]	
	88.128.681,00	[head/a]	
	325.958.614,79	[m³ feed water / a]	
	16.169.035.266,77	[m³ irrigation water / a]	total m3 / a
	16.494.993.881,57	[m³ water demand livestock total / a]	250.417.149.209,12

Western Africa		Winners		Livestock	Winners	
1	Millet	13.920.597	ha/a	Chicken	139	l/a/head
2	Sorghum	12.093.879	ha/a	Goats	3.699	l/a/head
3	Maize	8.209.658	ha/a	Sheep	2.613	l/a/head
Population		312.440.384	people			
prod mun WW		78.625.000	m3/a			
Treated mun ww		6.050.000	m3/a			

Western Africa	Millet planting date	[mm] actual irrigation requirement	Sorghum planting date	[mm] actual irrigation requirement	Maize planting date	[mm] actual irrigation requirement
Benin	1.3.	115,1	1.3.	41,3	1.3.	164,2
Burkina Faso	1.3.	391,4	1.3.	382,9	1.3.	484,3
Côte d'Ivoire	1.4.	1,1	1.4.	0,0	1.4.	0,0
Ghana	1.4.	1,2	1.4.	0,0	1.4.	0,0
Guinea	1.4.	1,3	1.4.	0,0	1.4.	0,0
Liberia	1.4.	1,1	1.4.	0,0	1.4.	0,0
Mali	1.4.	586,9	1.4.	667,2	1.4.	764,4
Mauritania	1.4.	647,6	1.4.	746,4	1.4.	851,2
Niger	1.4.	531,5	1.4.	537,3	1.4.	654,1
Nigeria	1.4.	1,2	1.4.	0,0	1.4.	0,0
Senegal	1.4.	308,4	1.4.	207,2	1.4.	295,1
Sierra Leone	1.4.	1,0	1.4.	0,0	1.4.	0,0
total		215,7		215,2		267,8

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Millet	30.019.767.430,50	Sorghum	26.025.019.784,75	Maize	21.983.411.709,50	78.028.198.924,75

waste water potential	Western Africa	
crop irrigation	0,00	
livestock	0,00	
total	0,00	

Western Africa			***Western Africa***		
Millet			**Sorghum**		
harvested area	13.920.597,00	[ha]		12.093.879,00	[ha]
cropwat result (avg. mm irr. demand)	215,65	[mm / a] | [l/m² / a]		215,19	[mm / a] | [l/m² / a]
	2.156.500,00	[l/ha / a]		2.151.916,67	[l/ha / a]
	2.156,50	[m³/ha / a]		2.151,92	[m³/ha / a]
Millet	30.019.767.430,50	[m³/a]	**Sorghum**	26.025.019.784,75	[m³/a]
tot irr dem for 3 main crops / a	78.028.198.924,75	[m³/a]		3.776.522.167,33	[m³/a]
treated ww in region	6.050.000,00	[m³/a]		6.050.000,00	[m³/a]
	0,02	% ww of irr. demand from ww		0,02	% ww of irr. demand from ww
ha crops irr. with treated ww	2.805,47	[ha]		2.811,45	[ha]
Millet	378,00	[kcal / 100g]	Sorghum	359,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.590.000,00	[kcal/ton]
	2.835.000,00	[kcal/ha]		4.895.563,33	[kcal/ha]
	0,0007607	[m³ irr. / kcal]		0,0004396	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	2,59	[p/ha]		4,47	[p/ha]
	0,39	[ha/p]		0,22	[ha/p]
which crop is most suitable to feed humanity			***which crop is most suitable to feed humanity***		
Millet	832,93	[m³ irr. water /p / a]	Sorghum	481,32	[m³ irr. water /p / a]
pop. pot. fed with treated ww	7.263,48	[p]		12.569,51	[p]
	0,00	% of people pot. fed		0,00	% of people pot. fed
which animal is most suitable to feed humanity			***which animal is most suitable to feed humanity***		
all animals fed with	**Millet**				
	Chicken			**Goats**	
meat	4.459,84	[kcal/head]		75.000,00	[kcal/head]
	245,52	[heads /p / a]		14,60	[heads /p / a]
	0,14	[m³/head animal feed water / a]		3,70	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		750.000,00	[kcal food for 1 head]
	33,92	[m³ irr. water/head animal food]		570,50	[m³ irr. water/head animal food]
	34,063	[m³/head total]		574,201	[m³/head total]
	8.363,36	[m³ irr, water / p / a]		8.383,34	[m³ irr, water / p / a]
	367.230.871,00	[head/a]		97.116.726,00	[head/a]
	50.879.072,11	[m³ feed water / a]		359.202.397,23	[m³ feed water / a]
	12.509.066.499,38	[m³ irrigation water / a]		55.764.551.502,79	[m³ irrigation water / a]
	12.559.945.571,49	[m³ water demand livestock total / a]		56.123.753.900,02	[m³ water demand livestock total / a]

Western Africa		
Maize		
	8.209.658,00	[ha]
	267,78	[mm / a] | [l/m² / a]
	2.677.750,00	[l/ha / a]
	2.677,75	[m³/ha / a]
Maize	21.983.411.709,50	[m³/a]
	3.776.522.167,33	[m³/a]
	6.050.000,00	[m³/a]
	0,03	% ww of irr. demand from ww
	2.259,36	[ha]
Maize	363,50	[kcal / 100g]
	3.635.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]
	0,0001970	[m³ irr. / kcal]
		[kcal/p/a]
	12,41	[p/ha]
	0,08	[ha/p]
which crop is most suitable to feed humanity		
Maize	215,75	[m³ irr. water /p / a]
Western Africa		
	28.041,55	[p]
	0,01	% of people pot. fed
which animal is most suitable to feed humanity		
	Sheep	
	178.568,73	[kcal/head]
	6,13	[heads /p / a]
	2,61	[m³/head animal feed water / a]
	1.785.687,30	[kcal food for 1 head]
	1.358,32	[m³ irr. water/head animal food]
	1.360,933	[m³/head total]
	8.345,36	[m³ irr, water / p / a]
	72.198.332,00	[head/a]
	188.683.120,85	[m³ feed water / a]
	98.257.056.819,85	[m³ irrigation water / a]
	98.445.739.940,70	[m³ water demand livestock total / a]

total m3 / a
167.129.439.412,21

Southern Africa		Winners			Livestock	Winners	
1	Maize		3.660.339	ha/a	Chicken	139	l/a/head
2	Wheat		963.300	ha/a	Cattle	14.418	l/a/head
3	Sorghum		261.972	ha/a	Goats	3.699	l/a/head
Population			50.749.476	people			
prod mun WW			528.154.167	m3/a			
Treated mun ww			265.250.000	m3/a			

Southern Africa	Maize planting date	[mm] actual irrigation requirement	Wheat planting date	[mm] actual irrigation requirement	Sorghum planting date	[mm] actual irrigation requirement
South Africa	1.10.	571,2	1.10.	497,6	1.10.	481,3
total		571,2		497,6		481,3

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Maize	20.907.856.368,00	Wheat	4.793.380.800,00	Sorghum	1.260.871.236,00	26.962.108.404,00

waste water potential	Southern Africa	
crop irrigation	0,01	
livestock	0,00	
total	0,00	

Southern Africa			*Southern Africa*		
Maize			**Wheat**		
harvested area	3.660.339,00	[ha]		963.300,00	[ha]
cropwat result (avg. mm irr. demand)	571,20	[mm / a] | [l/m² / a]		497,60	[mm / a] | [l/m² / a]
	5.712.000,00	[l/ha / a]		4.976.000,00	[l/ha / a]
	5.712,00	[m³/ha / a]		4.976,00	[m³/ha / a]
Maize	20.907.856.368,00	[m³/a]	**Wheat**	4.793.380.800,00	[m³/a]
tot irr dem for 3 main crops / a	26.962.108.404,00	[m³/a]		3.776.522.167,33	[m³/a]
treated ww in region	265.250.000,00	[m³/a]		265.250.000,00	[m³/a]
	1,27	% ww of irr. demand from ww		5,53	% ww of irr. demand from ww
ha crops irr. with treated ww	46.437,32	[ha]		53.305,87	[ha]
Maize	363,50	[kcal / 100g]	Wheat	364,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.640.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]		11.329.500,00	[kcal/ha]
	0,0004203	[m³ irr. / kcal]		0,0004392	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	12,41	[p/ha]		10,35	[p/ha]
	0,08	[ha/p]		0,10	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Maize	460,23	[m³ irr. water /p / a]	Wheat	480,93	[m³ irr. water /p / a]
Southern Africa					
pop. pot.fed with treated ww	576.346,84	[p]		551.533,18	[p]
	1,14	% of people pot. fed		1,09	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Maize**				
	Chicken			**Cattle**	
meat	4.459,84	[kcal/head]		847.973,25	[kcal/head]
	245,52	[heads /p / a]		1,29	[heads /p / a]
	0,14	[m³/head animal feed water / a]		14,42	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		8.479.732,50	[kcal food for 1 head]
	18,74	[m³ irr. water/head animal food]		3.564,01	[m³ irr. water/head animal food]
	18,883	[m³/head total]		3.578,432	[m³/head total]
	4.636,28	[m³ irr, water / p / a]		4.620,88	[m³ irr, water / p / a]
	138.608.484,00	[head/a]		31.260.110,00	[head/a]
	19.203.916,69	[m³ feed water / a]		450.692.635,93	[m³ feed water / a]
	2.617.367.249,79	[m³ irrigation water / a]		111.862.190.149,53	[m³ irrigation water / a]
	2.636.571.166,48	[m³ water demand livestock total / a]		112.312.882.785,46	[m³ water demand livestock total / a]

Southern Africa			
Sorghum			
	261.972,00	[ha]	
	481,30	[mm / a] | [l/m² / a]	
	4.813.000,00	[l/ha / a]	
	4.813,00	[m³/ha / a]	
Sorghum	1.260.871.236,00	[m³/a]	
	3.776.522.167,33	[m³/a]	
	265.250.000,00	[m³/a]	
	21,04	% ww of irr. demand from ww	
	55.111,16	[ha]	
Sorghum	359,00	[kcal / 100g]	
	3.590.000,00	[kcal/ton]	
	4.895.563,33	[kcal/ha]	
	0,0009831	[m³ irr. / kcal]	
		[kcal/p/a]	
	4,47	[p/ha]	
	0,22	[ha/p]	
which crop is most suitable to feed humanity			
Sorghum	1.076,53	[m³ irr. water /p / a]	
	246.392,84	[p]	
	0,49	% of people pot. fed	
which animal is most suitable to feed humanity			
	Goats		
	75.000,00	[kcal/head]	
	14,60	[heads /p / a]	
	3,70	[m³/head animal feed water / a]	
	750.000,00	[kcal food for 1 head]	
	315,22	[m³ irr. water/head animal food]	
	318,922	[m³/head total]	
	4.656,26	[m³ irr, water / p / a]	
	19.234.323,00	[head/a]	
	71.141.349,34	[m³ feed water / a]	
	6.134.252.441,95	[m³ irrigation water / a]	total m3 / a
	6.205.393.791,29	[m³ water demand livestock total / a]	121.154.847.743,23

Northern America		Winners		
1	Wheat		32.282.802	ha/a
2	Triticale		31.154.201	ha/a
3	Barley		5.653.210	ha/a
population			310.785.501	people
prod mun WW			24.671.111.111	m3/a
Treated mun ww			17.350.000.000	m3/a

Livestock	Winners	
Chicken	139	l/a/head
Turkey	175	l/a/head
Cattle	14.418	l/a/head

Northern America	Wheat planting date	[mm] actual irrigation requirement	Triticale planting date	[mm] actual irrigation requirement	Barley planting date	[mm] actual irrigation requirement
Canada	1.4.	201,6		n/a - cropwat	1.4.	223,2
United States of America	1.4.	508,2		n/a - cropwat	1.4.	510,6
total		354,9				366,9

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	114.577.044.765,00	Triticale	0,00	Barley	20.741.627.490,00	135.318.672.255,00

waste water potential	Northern America	
crop irrigation	0,13	
livestock	0,05	
total	0,04	

Northern America			*Northern America*		
Wheat			**Triticale**		
harvested area	32.282.802,00	[ha]		31.154.201,00	[ha]
cropwat result (avg. mm irr. demand)	354,92	[mm / a] | [l/m^2 / a]		-	[mm / a] | [l/m^2 / a]
	3.549.166,67	[l/ha / a]		-	[l/ha / a]
	3.549,17	[m^3/ha / a]		-	[m^3/ha / a]
Wheat	114.577.044.765,00	[m^3/a]	**Triticale**	0,00	[m^3/a]
tot irr dem for 3 main crops / a	135.318.672.255,00	[m^3/a]		135.318.672.255,00	[m^3/a]
treated ww in region	17.350.000.000,00	[m^3/a]		17.350.000.000,00	[m^3/a]
	15,14	% ww of irr. demand from ww		#DIV/0!	% ww of irr. demand from ww
ha crops irr. with treated ww	4.888.471,47	[ha]		#DIV/0!	[ha]
Wheat	364,00	[kcal / 100g]	Triticale	336,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.360.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]		8.433.600,00	[kcal/ha]
	0,0003133	[m^3 irr. / kcal]		-	[m^3 irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,35	[p/ha]		7,70	[p/ha]
	0,10	[ha/p]		0,13	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Wheat	343,03	[m^3 irr. water /p / a]	Triticale	-	[m^3 irr. water /p / a]
pop. pot.fed with treated ww	50.578.938,40	[p]		#DIV/0!	[p]
	16,27	% of people pot. fed		#DIV/0!	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Wheat**				
	Chicken			**Turkey**	
meat	4.459,84	[kcal/head]		10.456,25	[kcal/head]
	245,52	[heads /p / a]		104,72	[heads /p / a]
	0,139	[m^3/head animal feed water / a]		0,175	[m^3/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		104.562,50	[kcal food for 1 head]
	13,97	[m^3 irr. water/head animal food]		32,76	[m^3 irr. water/head animal food]
	14,110	[m^3/head total]		32,932	[m^3/head total]
	3.464,30	[m^3 irr, water / p / a]		3.448,66	[m^3 irr, water / p / a]
	1.909.557.613,00	[head/a]		270.998.226,00	[head/a]
	264.565.229,04	[m^3 feed water / a]		47.547.579,72	[m^3 feed water / a]
	26.943.451.431,77	[m^3 irrigation water / a]		8.924.380.721,37	[m^3 irrigation water / a]
	27.208.016.660,80	[m^3 water demand livestock total / a]		8.971.928.301,09	[m^3 water demand livestock total / a]

Northern America			
Barley			
	5.653.210,00	[ha]	
	366,90	[mm / a] | [l/m² / a]	
	3.669.000,00	[l/ha / a]	
	3.669,00	[m³/ha / a]	
Barley	20.741.627.490,00	[m³/a]	
	135.318.672.255,00	[m³/a]	
	17.350.000.000,00	[m³/a]	
	83,65	% ww of irr. demand from ww	
	4.728.808,94	[ha]	
Barley	404,00	[kcal / 100g]	
	4.040.000,00	[kcal/ton]	
	14.746.000,00	[kcal/ha]	
	0,0002488	[m³ irr. / kcal]	
		[kcal/p/a]	
	13,47	[p/ha]	
	0,07	[ha/p]	
which crop is most suitable to feed humanity			
Barley	272,45	[m³ irr. water /p / a]	
Northern America			
	63.681.293,72	[p]	
	20,49	% of people pot. fed	
which animal is most suitable to feed humanity			
	Cattle		
	847.973,25	[kcal/head]	
	1,29	[heads /p / a]	
	14,418	[m³/head animal feed water / a]	
	8.479.732,50	[kcal food for 1 head]	
	2.656,43	[m³ irr. water/head animal food]	
	2.670,844	[m³/head total]	
	3.448,90	[m³ irr, water / p / a]	
	109.064.458,00	[head/a]	
	1.572.436.823,22	[m³ feed water / a]	
	291.294.152.295,08	[m³ irrigation water / a]	total m3 / a
	292.866.589.118,30	[m³ water demand livestock total / a]	329.046.534.080,19

Central America		Winners			Livestock	Winners	
	1	Maize	8.952.366	ha/a	Chicken	139	l/a/head
	2	Sorghum	1.958.999	ha/a	Cattle	14.418	l/a/head
	3	Wheat	778.317	ha/a	Pigs	3.346	l/a/head
population			137.018.666	people			
prod mun WW			232.533.333	m3/a			
Treated mun ww			23.570.000	m3/a			

Central America	Maize	[mm]	Sorghum	[mm]	Wheat	[mm]
	planting date	actual irrigation requirement	planting date	actual irrigation requirement	planting date	actual irrigation requirement
Costa Rica	1.1.	4,3	1.1.	3,1	1.1.	3,7
El Salvador	1.1.	405,0	1.1.	349,3	1.1.	359,8
Guatemala	1.1.	115,1	1.1.	86,3	1.1.	159,95
Honduras	1.1.	118,2	1.1.	233,7	1.1.	246,8
Mexico	1.1.	311,0	1.1.	271,6	1.1.	296,9
Nicaragua	1.1.	657,3	1.1.	581,3	1.1.	611,2
Panama	1.1.	448,7	1.1.	379,8	1.1.	405,3
total		294,2		272,2		297,7

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Maize	26.339.779.136,14	Sorghum	5.331.555.707,00	Wheat	2.316.771.738,64	33.988.106.581,79

waste water potential	prod mun WW	
crop irrigation	0,00	
livestock	0,00	
total	0,00	

Central America			*Central America*		
Maize			**Sorghum**		
harvested area	8.952.366,00	[ha]		1.958.999,00	[ha]
cropwat result (avg. mm irr. demand)	294,22	[mm / a] | [l/m² / a]		272,16	[mm / a] | [l/m² / a]
	2.942.214,29	[l/ha / a]		2.721.571,43	[l/ha / a]
	2.942,21	[m³/ha / a]		2.721,57	[m³/ha / a]
Maize	26.339.779.136,14	[m³/a]	**Sorghum**	5.331.555.707,00	[m³/a]
tot irr dem for 3 main crops / a	33.988.106.581,79	[m³/a]		33.988.106.581,79	[m³/a]
treated ww in region	23.570.000,00	[m³/a]		23.570.000,00	[m³/a]
	0,09	% ww of irr. demand from ww		0,44	% ww of irr. demand from ww
ha crops irr. with treated ww	8.010,97	[ha]		8.660,44	[ha]
Maize	363,50	[kcal / 100g]	Sorghum	359,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.590.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]		4.895.563,33	[kcal/ha]
	0,0002165	[m³ irr. / kcal]		0,0005559	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	12,41	[p/ha]		4,47	[p/ha]
	0,08	[ha/p]		0,22	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Maize	237,06	[m³ irr. water /p / a]	Sorghum	608,74	[m³ irr. water /p / a]
Central America					
pop. pot.fed with treated ww	99.426,47	[p]		38.719,38	[p]
	0,07	% of people pot. fed		0,03	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Maize**				
	Chicken			**Cattle**	
meat	4.459,84	[kcal/head]		847.973,25	[kcal/head]
	245,52	[heads /p / a]		1,29	[heads /p / a]
	0,139	[m³/head animal feed water / a]		14,418	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		8.479.732,50	[kcal food for 1 head]
	9,66	[m³ irr. water/head animal food]		1.835,80	[m³ irr. water/head animal food]
	9,794	[m³/head total]		1.850,219	[m³/head total]
	2.404,61	[m³ irr, water / p / a]		2.389,21	[m³ irr, water / p / a]
	512.177.613,00	[head/a]		44.562.309,00	[head/a]
	70.961.141,24	[m³ feed water / a]		642.477.090,01	[m³ feed water / a]
	5.016.155.085,42	[m³ irrigation water / a]		82.450.010.175,08	[m³ irrigation water / a]
	5.087.116.226,66	[m³ water demand livestock total / a]		83.092.487.265,09	[m³ water demand livestock total / a]

Central America			
Wheat			
	778.317,00	[ha]	
	297,66	[mm / a] | [l/m² / a]	
	2.976.642,86	[l/ha / a]	
	2.976,64	[m³/ha / a]	
Wheat	2.316.771.738,64	[m³/a]	
	33.988.106.581,79	[m³/a]	
	23.570.000,00	[m³/a]	
	1,02	% ww of irr. demand from ww	
	7.918,32	[ha]	
Wheat	364,00	[kcal / 100g]	
	3.640.000,00	[kcal/ton]	
	11.329.500,00	[kcal/ha]	
	0,0002627	[m³ irr. / kcal]	
		[kcal/p/a]	
	10,35	[p/ha]	
	0,10	[ha/p]	
which crop is most suitable to feed humanity			
Wheat	287,69	[m³ irr. water /p / a]	
	81.927,46	[p]	
	0,06	% of people pot. fed	
which animal is most suitable to feed humanity			
	Pigs		
	83.765,50	[kcal/head]	
	13,07	[heads/p / a]	
	3,346	[m³/head animal feed water / a]	
	837.655,00	[kcal food for 1 head]	
	181,35	[m³ irr. water/head animal food]	
	184,692	[m³/head total]	
	2.414,33	[m³ irr, water / p / a]	
	19.717.170,00	[head/a]	
	65.970.364,63	[m³ feed water / a]	
	3.641.605.734,87	[m³ irrigation water / a]	total m3 / a
	3.707.576.099,49	[m³ water demand livestock total / a]	91.887.179.591,24

Caribbean		Winners			Livestock	Winners	
1	Maize		453.943	ha/a	Chicken	139	l/a/head
2	Rice, paddy		360.626	ha/a	Cattle	14.418	l/a/head
3	Sorghum		132.034	ha/a	Pigs	3.346	l/a/head
population			36.110.619	people			
prod mun WW			279.875.000	m3/a			
Treated mun ww			49.800.000	m3/a			

Caribbean	Maize planting date	[mm] actual irrigation requirement	Rice, paddy planting date	[mm] actual irrigation requirement	Sorghum planting date	[mm] actual irrigation requirement
Cuba	1.1.	276,5	1.5.	-15,6	1.1.	95,15
Dominican Republic	1.1.	55,4	1.5.	90,3	1.1.	11,9
Haiti	1.1.	165,3	1.5.	-601,3	1.1.	17,4
Puerto Rico	1.1.	222,9	1.5.	162,3	1.1.	164,8
total		180,0		126,3		72,3

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Maize	817.210.885,75	Rice, paddy	455.470.638,00	Sorghum	95.477.086,25	1.368.158.610,00

waste water potential	Caribbean	
crop irrigation	0,04	
livestock	0,00	
total	0,00	

Caribbean			***Caribbean***		
Maize			**Rice, paddy**		
harvested area	453.943,00	[ha]		360.626,00	[ha]
cropwat result (avg. mm irr. demand)	180,03	[mm / a] | [l/m² / a]		126,30	[mm / a] | [l/m² / a]
	1.800.250,00	[l/ha / a]		1.263.000,00	[l/ha / a]
	1.800,25	[m³/ha / a]		1.263,00	[m³/ha / a]
Maize	817.210.885,75	[m³/a]	**Rice, paddy**	455.470.638,00	[m³/a]
tot irr dem for 3 main crops / a	1.368.158.610,00	[m³/a]		1.368.158.610,00	[m³/a]
treated ww in region	49.800.000,00	[m³/a]		49.800.000,00	[m³/a]
	6,09	% ww of irr. demand from ww		10,93	% ww of irr. demand from ww
ha crops irr. with treated ww	27.662,82	[ha]		39.429,93	[ha]
Maize	363,50	[kcal / 100g]	Rice, paddy	364,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.640.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]		11.963.466,67	[kcal/ha]
	0,0001325	[m³ irr. / kcal]		0,0001056	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	12,41	[p/ha]		10,93	[p/ha]
	0,08	[ha/p]		0,09	[ha/p]
which crop is most suitable to feed humanity			***which crop is most suitable to feed humanity***		
Maize	145,05	[m³ irr. water /p / a]	Rice, paddy Caribbean	115,60	[m³ irr. water /p / a]
pop. pot.fed with treated ww	343.331,18	[p]		430.793,28	[p]
	0,95	% of people pot. fed		1,19	% of people pot. fed
which animal is most suitable to feed humanity			***which animal is most suitable to feed humanity***		
all animals fed with	**Maize**				
	Chicken			**Cattle**	
meat	4.459,84	[kcal/head]		847.973,25	[kcal/head]
	245,52	[heads /p / a]		1,29	[heads /p / a]
	0,139	[m³/head animal feed water / a]		14,418	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		8.479.732,50	[kcal food for 1 head]
	5,91	[m³ irr. water/head animal food]		1.123,27	[m³ irr. water/head animal food]
	6,046	[m³/head total]		1.137,687	[m³/head total]
	1.484,51	[m³ irr, water / p / a]		1.469,11	[m³ irr, water / p / a]
	192.524.903,00	[head/a]		9.092.309,00	[head/a]
	26.673.924,22	[m³ feed water / a]		131.088.365,01	[m³ feed water / a]
	1.164.060.688,22	[m³ irrigation water / a]		10.344.205.605,13	[m³ irrigation water / a]
	1.190.734.612,43	[m³ water demand livestock total / a]		10.475.293.970,14	[m³ water demand livestock total / a]

Caribbean			
Sorghum			
	132.034,00	[ha]	
	72,31	[mm / a] | [l/m² / a]	
	723.125,00	[l/ha / a]	
	723,13	[m³/ha / a]	
Sorghum	95.477.086,25	[m³/a]	
	1.368.158.610,00	[m³/a]	
	49.800.000,00	[m³/a]	
	52,16	% ww of irr. demand from ww	
	68.867,76	[ha]	
Sorghum	359,00	[kcal / 100g]	
	3.590.000,00	[kcal/ton]	
	4.895.563,33	[kcal/ha]	
	0,0001477	[m³ irr. / kcal]	
		[kcal/p/a]	
	4,47	[p/ha]	
	0,22	[ha/p]	
which crop is most suitable to feed humanity			
Sorghum	161,74	[m³ irr. water /p / a]	
	307.896,34	[p]	
	0,85	% of people pot. fed	
which animal is most suitable to feed humanity			
	Pigs		
	83.765,50	[kcal/head]	
	13,07	[heads /p / a]	
	3,346	[m³/head animal feed water / a]	
	837.655,00	[kcal food for 1 head]	
	110,96	[m³ irr. water/head animal food]	
	114,306	[m³/head total]	
	1.494,23	[m³ irr, water / p / a]	
	3.633.988,00	[head/a]	
	12.158.718,18	[m³ feed water / a]	
	415.386.690,94	[m³ irrigation water / a]	total m3 / a
	427.545.409,12	[m³ water demand livestock total / a]	12.093.573.991,69

Southern America		Winners			Livestock	Winners	
	1	Maize	19.340.880	ha/a	Chicken	139	l/a/head
	2	Wheat	8.544.095	ha/a	Cattle	14.418	l/a/head
	3	Rice, paddy	5.480.486	ha/a	Sheep	2.613	l/a/head
population			331.282.682	people			
prod mun WW			1.809.726.667	m3/a			
Treated mun ww			538.700.000	m3/a			

Southern America	Maize	[mm]	Wheat	[mm]	Rice, paddy	[mm]
	planting date	actual irrigation requirement	planting date	actual irrigation requirement	planting date	actual irrigation requirement
Argentina	1.8.	307,6	1.5.	87,9	1.5.	124,56
Bolivia (Plurinational State of)	1.8.	391,8	1.5.	201,0	1.5.	201,0
Brazil	1.8.	64,68	1.5.	293,7	1.5.	296,3
Chile	1.8.	259,7	1.5.	0,0	1.5.	-101,5
Ecuador	1.8.	76,5	1.5.	67,6	1.5.	-409,1
Paraguay	1.8.	25,7	1.5.	91,9	1.5.	0,5
Peru	1.8.	0,0	1.5.	0,0	1.5.	-356,8
Uruguay	1.8.	41,9	1.5.	0,0	1.5.	-265,2
Venezuela (Bolivarian Republic of)	1.8.	130,4	1.5.	0,0	1.5.	-386,8
total		144,3		82,5		155,6

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Maize	27.899.864.096,00	Wheat	7.044.796.196,28	Rice, paddy	8.527.818.898,87	43.472.479.191,14

waste water potential	Southern America	
crop irrigation	0,01	
livestock	0,00	
total	0,00	

Southern America			*Southern America*		
Maize			**Wheat**		
harvested area	19.340.880,00	[ha]		8.544.095,00	[ha]
cropwat result (avg. mm irr. demand)	144,25	[mm / a] | [l/m² / a]		82,45	[mm / a] | [l/m² / a]
	1.442.533,33	[l/ha / a]		824.522,22	[l/ha / a]
	1.442,53	[m³/ha / a]		824,52	[m³/ha / a]
Maize	27.899.864.096,00	[m³/a]	**Wheat**	7.044.796.196,28	[m³/a]
tot irr dem for 3 main crops / a	43.472.479.191,14	[m³/a]		43.472.479.191,14	[m³/a]
treated ww in region	538.700.000,00	[m³/a]		538.700.000,00	[m³/a]
	1,93	% ww of irr. demand from ww		7,65	% ww of irr. demand from ww
ha crops irr. with treated ww	373.440,24	[ha]		653.348,07	[ha]
Maize	363,50	[kcal / 100g]	Wheat	364,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.640.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]		11.329.500,00	[kcal/ha]
	0,0001061	[m³ irr. / kcal]		0,0000728	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	12,41	[p/ha]		10,35	[p/ha]
	0,08	[ha/p]		0,10	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Maize	116,23	[m³ irr. water /p / a]	Wheat	79,69	[m³ irr. water /p / a]
			Southern America		
pop. pot.fed with treated ww	4.634.873,02	[p]		6.759.915,00	[p]
	1,40	% of people pot. fed		2,04	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Maize**				
	Chicken			**Cattle**	
meat	4.459,84	[kcal/head]		847.973,25	[kcal/head]
	245,52	[heads /p / a]		1,29	[heads /p / a]
	0,139	[m³/head animal feed water / a]		14,418	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		8.479.732,50	[kcal food for 1 head]
	4,73	[m³ irr. water/head animal food]		900,07	[m³ irr. water/head animal food]
	4,872	[m³/head total]		914,489	[m³/head total]
	1.196,29	[m³ irr, water / p / a]		1.180,89	[m³ irr, water / p / a]
	1.655.884.613,00	[head/a]		316.728.651,00	[head/a]
	229.419.363,37	[m³ feed water / a]		4.566.435.325,79	[m³ feed water / a]
	8.068.125.166,11	[m³ irrigation water / a]		289.644.971.115,58	[m³ irrigation water / a]
	8.297.544.529,48	[m³ water demand livestock total / a]		294.211.406.441,37	[m³ water demand livestock total / a]

Southern America			
Rice, paddy			
	5.480.486,00	[ha]	
	155,60	[mm / a] | [l/m² / a]	
	1.556.033,33	[l/ha / a]	
	1.556,03	[m³/ha / a]	
Rice, paddy	8.527.818.898,87	[m³/a]	
	43.472.479.191,14	[m³/a]	
	538.700.000,00	[m³/a]	
	6,32	% ww of irr. demand from ww	
	346.200,81	[ha]	
Rice, paddy	364,00	[kcal / 100g]	
	3.640.000,00	[kcal/ton]	
	11.963.466,67	[kcal/ha]	
	0,0001301	[m³ irr. / kcal]	
		[kcal/p/a]	
	10,93	[p/ha]	
	0,09	[ha/p]	
which crop is most suitable to feed humanity			
Rice, paddy	142,42	[m³ irr. water /p / a]	
	3.782.430,91	[p]	
	1,14	% of people pot. fed	
which animal is most suitable to feed humanity			
	Sheep		
	178.568,73	[kcal/head]	
	6,13	[heads /p / a]	
	2,613	[m³/head animal feed water / a]	
	1.785.687,30	[kcal food for 1 head]	
	189,54	[m³ irr. water/head animal food]	
	192,153	[m³/head total]	
	1.178,30	[m³ irr, water / p / a]	
	78.593.578,00	[head/a]	
	205.396.456,75	[m³ feed water / a]	
	15.102.007.787,46	[m³ irrigation water / a]	total m3 / a
	15.307.404.244,20	[m³ water demand livestock total / a]	317.816.355.215,06

Western Asia		Winners			Livestock	Winners	
1	Wheat		13.004.656	ha/a	Chicken	139	l/a/head
2	Barley		6.344.456	ha/a	Sheep	2.613	l/a/head
3	Maize		920.556	ha/a	Goat	3.699	l/a/head

population	203.243.690	people
prod mun WW	720.078.011	m3/a
Treated mun ww	323.800.000	m3/a

Western Asia	Wheat	[mm]	Barley	[mm]	Maize	[mm]
	planting date	actual irrigation requirement	planting date	actual irrigation requirement	planting date	actual irrigation requirement
Azerbaijan	1.3.	319,8	1.3.	288,5	1.4.	451,5
Iraq	1.3.	683,6	1.3.	626,6	1.4.	928,1
Israel	1.3.	646,4	1.3.	586,2	1.4.	880,2
Kuwait	1.3.	989,5	1.3.	899,9	1.4.	1.327,4
Oman	1.3.	1.157,9	1.3.	1.148,3	1.4.	1.302,3
Saudi Arabia	1.3.	369,6	1.3.	358,9	1.4.	459,0
Syrian Arab Republic	1.3.	795,5	1.3.	723,5	1.4.	1.107,4
Turkey	1.3.	218,9	1.3.	189,3	1.4.	361,0
United Arab Emirates	1.3.	813,3	1.3.	802,9	1.4.	955,5
Yemen	1.3.	441,8	1.3.	446,2	1.4.	422,5
total		643,6		607,0		819,5

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	83.701.867.412,80	Barley	38.512.751.256,80	Maize	7.543.864.364,40	129.758.483.034,00

waste water potential	Western Asia	
crop irrigation	0,00	
livestock	0,00	
total	0,00	

Western Asia			*Western Asia*		
Wheat			**Barley**		
harvested area	13.004.656,00	[ha]		6.344.456,00	[ha]
cropwat result (avg. mm irr. demand)	643,63	[mm / a] | [l/m^2 / a]		607,03	[mm / a] | [l/m^2 / a]
	6.436.300,00	[l/ha / a]		6.070.300,00	[l/ha / a]
	6.436,30	[m^3/ha / a]		6.070,30	[m^3/ha / a]
Wheat	83.701.867.412,80	[m^3/a]	**Barley**	38.512.751.256,80	[m^3/a]
tot irr dem for 3 main crops / a	129.758.483.034,00	[m^3/a]		129.758.483.034,00	[m^3/a]
treated ww in region	323.800.000,00	[m^3/a]		323.800.000,00	[m^3/a]
	0,39	% ww of irr. demand from ww		0,84	% ww of irr. demand from ww
ha crops irr. with treated ww	50.308,41	[ha]		53.341,68	[ha]
Wheat	364,00	[kcal / 100g]	Barley	345,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.450.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]		8.006.156,25	[kcal/ha]
	0,0005681	[m^3 irr. / kcal]		0,0007582	[m^3 irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,35	[p/ha]		7,31	[p/ha]
	0,10	[ha/p]		0,14	[ha/p]
which crop is most suitable to feed humanity			***which crop is most suitable to feed humanity***		
Wheat	622,07	[m^3 irr. water /p / a]	Barley	830,23	[m^3 irr. water /p / a]
pop. pot.fed with treated ww	520.519,72	[p]		390.010,80	[p]
	0,26	% of people pot. fed		0,19	% of people pot. fed
which animal is most suitable to feed humanity			***which animal is most suitable to feed humanity***		
all animals fed with	**Wheat**	Western Asia			
	Chicken			**Sheep**	
meat	4.459,84	[kcal/head]		178.568,73	[kcal/head]
	245,52	[heads /p / a]		6,13	[heads /p / a]
	0,139	[m^3/head animal feed water / a]		2,613	[m^3/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		1.785.687,30	[kcal food for 1 head]
	25,34	[m^3 irr. water/head animal food]		1.014,45	[m^3 irr. water/head animal food]
	25,475	[m^3/head total]		1.017,064	[m^3/head total]
	6.254,72	[m^3 irr, water / p / a]		6.236,73	[m^3 irr, water / p / a]
	626.812.581,00	[head/a]		81.226.958,00	[head/a]
	86.843.577,24	[m^3 feed water / a]		212.278.532,04	[m^3 feed water / a]
	15.968.014.430,93	[m^3 irrigation water / a]		82.613.022.671,17	[m^3 irrigation water / a]
	16.054.858.008,17	[m^3 water demand livestock total / a]		82.825.301.203,21	[m^3 water demand livestock total / a]

Western Asia			
Maize			
	920.556,00	[ha]	
	819,49	[mm / a] | [l/m² / a]	
	8.194.900,00	[l/ha / a]	
	8.194,90	[m³/ha / a]	
Maize	7.543.864.364,40	[m³/a]	
	129.758.483.034,00	[m³/a]	
	323.800.000,00	[m³/a]	
	4,29	% ww of irr. demand from ww	
	39.512,38	[ha]	
Maize	364,00	[kcal / 100g]	
	3.640.000,00	[kcal/ton]	
	11.963.466,67	[kcal/ha]	
	0,0006850	[m³ irr. / kcal]	
		[kcal/p/a]	
	10,93	[p/ha]	
	0,09	[ha/p]	
which crop is most suitable to feed humanity			
Maize	750,07	[m³ irr. water /p / a]	
	431.694,10	[p]	
	0,21	% of people pot. fed	
which animal is most suitable to feed humanity			
	Goat		
	75.000,00	[kcal/head]	
	14,60	[heads /p / a]	
	3,699	[m³/head animal feed water / a]	
	750.000,00	[kcal food for 1 head]	
	426,08	[m³ irr. water/head animal food]	
	429,774	[m³/head total]	
	6.274,71	[m³ irr, water / p / a]	
	27.858.609,00	[head/a]	
	103.039.708,49	[m³ feed water / a]	
	11.972.916.916,66	[m³ irrigation water / a]	total m3 / a
	12.075.956.625,15	[m³ water demand livestock total / a]	110.956.115.836,53

Central Asisa		Winners			Livestock	Winners	
1	Wheat		14.687.058	ha/a	Chicken	139	l/a/head
2	Barley		2.774.056	ha/a	Sheep	2.613	l/a/head
3	Rice, paddy		253.588	ha/a	Cattle	14.418	l/a/head

population	56.808.146	people
prod mun WW	1.137.530.000	m3/a
Treated mun ww	190.600.000	m3/a

Central Asisa	Wheat	[mm]	Barley	[mm]	Rice, paddy	[mm]
	planting date	actual irrigation requirement	planting date	actual irrigation requirement	planting date	actual irrigation requirement
Uzbekistan	1.5.	836,8	1.5.	862,6	1.5.	1115,8
total		836,8		862,6		1.115,8

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	122.901.301.344,00	Barley	23.929.007.056,00	Rice, paddy	2.829.534.904,00	149.659.843.304,00

waste water potential	Central Asisa	
crop irrigation	0,00	
livestock	0,00	
total	0,00	

Central Asisa			*Central Asisa*		
Wheat			**Barley**		
harvested area	14.687.058,00	[ha]		2.774.056,00	[ha]
cropwat result (avg. mm irr. demand)	836,80	[mm / a] | [l/m² / a]		862,60	[mm / a] | [l/m² / a]
	8.368.000,00	[l/ha / a]		8.626.000,00	[l/ha / a]
	8.368,00	[m³/ha / a]		8.626,00	[m³/ha / a]
Wheat	122.901.301.344,00	[m³/a]	**Barley**	23.929.007.056,00	[m³/a]
tot irr dem for 3 main crops / a	149.659.843.304,00	[m³/a]		#REF!	[m³/a]
treated ww in region	190.600.000,00	[m³/a]		190.600.000,00	[m³/a]
	0,16	% ww of irr. demand from ww		0,80	% ww of irr. demand from ww
ha crops irr. with treated ww	22.777,25	[ha]		22.095,99	[ha]
Wheat	363,50	[kcal / 100g]	Barley	364,00	[kcal / 100g]
	3.635.000,00	[kcal/ton]		3.640.000,00	[kcal/ton]
	13.590.356,25	[kcal/ha]		11.329.500,00	[kcal/ha]
	0,0006157	[m³ irr. / kcal]		0,0007614	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	12,41	[p/ha]		10,35	[p/ha]
	0,08	[ha/p]		0,10	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Wheat	674,23	[m³ irr. water /p / a]	Barley	833,71	[m³ irr. water /p / a]
pop. pot.fed with treated ww	282.694,88	[p]		228.617,81	[p]
	0,50	% of people pot. fed		0,40	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Wheat**	Central Asisa			
	Chicken			**Sheep**	
meat	4.459,84	[kcal/head]		847.973,25	[kcal/head]
	245,52	[heads /p / a]		1,29	[heads /p / a]
	0,14	[m³/head animal feed water / a]		2,61	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		8.479.732,50	[kcal food for 1 head]
	27,46	[m³ irr. water/head animal food]		5.221,23	[m³ irr. water/head animal food]
	27,599	[m³/head total]		5.223,845	[m³/head total]
	6.776,27	[m³ irr, water / p / a]		6.745,63	[m³ irr, water / p / a]
	75.417.923,00	[head/a]		43.601.465,00	[head/a]
	10.448.996,11	[m³ feed water / a]		113.948.068,63	[m³ feed water / a]
	2.081.470.825,10	[m³ irrigation water / a]		227.767.307.933,59	[m³ irrigation water / a]
	2.091.919.821,21	[m³ water demand livestock total / a]		227.881.256.002,22	[m³ water demand livestock total / a]

Central Asisa			
Rice, paddy			
	253.588,00	[ha]	
	1.115,80	[mm / a] | [l/m² / a]	
	11.158.000,00	[l/ha / a]	
	11.158,00	[m³/ha / a]	
Rice, paddy	2.829.534.904,00	[m³/a]	
	#REF!	[m³/a]	
	190.600.000,00	[m³/a]	
	6,74	% ww of irr. demand from ww	
	17.081,91	[ha]	
Rice, paddy	364,00	[kcal / 100g]	
	3.640.000,00	[kcal/ton]	
	11.963.466,67	[kcal/ha]	
	0,0009327	[m³ irr. / kcal]	
		[kcal/p/a]	
	10,93	[p/ha]	
	0,09	[ha/p]	
which crop is most suitable to feed humanity			
Rice, paddy	1.021,28	[m³ irr. water /p / a]	
	186.629,14	[p]	
	0,33	% of people pot. fed	
which animal is most suitable to feed humanity			
	Cattle		
	847.973,25	[kcal/head]	
	1,29	[heads /p / a]	
	14,42	[m³/head animal feed water / a]	
	8.479.732,50	[kcal food for 1 head]	
	5.221,23	[m³ irr. water/head animal food]	
	5.235,649	[m³/head total]	
	6.760,87	[m³ irr, water / p / a]	
	17.649.538,00	[head/a]	
	254.462.214,12	[m³ feed water / a]	
	92.406.793.007,69	[m³ irrigation water / a]	total m3 / a
	92.661.255.221,80	[m³ water demand livestock total / a]	322.634.431.045,24

Eastern Asia		Winners			Livestock	Winners	
1	Rice, paddy		34.101.932	ha/a	Chicken	139	l/a/head
2	Maize		28.408.576	ha/a	Duck	256	l/a/head
3	Wheat		26.973.740	ha/a	Pig	3.346	l/a/head
population			1.351.175.283	people			
prod mun WW			14.019.375.000	m3/a			
Treated mun ww			11.025.000.000	m3/a			

Eastern Asia	Rice, paddy planting date	[mm] actual irrigation requirement	Maize planting date	[mm] actual irrigation requirement	Wheat planting date	[mm] actual irrigation requirement
China	1.5.	117,5	1.4.	223,5	1.3.	202,3
Japan	1.5.	-277,5	1.4.	0,0	1.3.	1,5
Mongolia	1.5.	446,0	1.4.	343,5	1.3.	312,8
Republic of Korea	1.5.	-208,6	1.4.	-10,8	1.3.	8,4
total		281,8		189,0		131,2

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Rice, paddy	96.086.456.151,50	Maize	53.687.473.877,33	Wheat	35.401.347.891,25	185.175.277.920,08

waste water potential	Eastern Asia	
crop irrigation	0,06	
livestock	0,06	
total	0,03	

Eastern Asia			*Eastern Asia*		
Rice, paddy			**Maize**		
harvested area	34.101.932,00	[ha]		28.408.576,00	[ha]
cropwat result (avg. mm irr. demand)	281,76	[mm / a] | [l/m² / a]		188,98	[mm / a] | [l/m² / a]
	2.817.625,00	[l/ha / a]		1.889.833,33	[l/ha / a]
	2.817,63	[m³/ha / a]		1.889,83	[m³/ha / a]
Rice, paddy	96.086.456.151,50	[m³/a]	**Maize**	53.687.473.877,33	[m³/a]
tot irr dem for 3 main crops / a	185.175.277.920,08	[m³/a]		185.175.277.920,08	[m³/a]
treated ww in region	11.025.000.000,00	[m³/a]		11.025.000.000,00	[m³/a]
	11,47	% ww of irr. demand from ww		20,54	% ww of irr. demand from ww
ha crops irr. with treated ww	3.912.869,88	[ha]		5.833.847,78	[ha]
Rice, paddy	364,00	[kcal / 100g]	Maize	363,50	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.635.000,00	[kcal/ton]
	11.963.466,67	[kcal/ha]		13.590.356,25	[kcal/ha]
	0,0002355	[m³ irr. / kcal]		0,0001391	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,93	[p/ha]		12,41	[p/ha]
	0,09	[ha/p]		0,08	[ha/p]
which crop is most suitable to feed humanity			***which crop is most suitable to feed humanity***		
Rice, paddy	257,89	[m³ irr. water /p / a]	Maize	152,27	[m³ irr. water /p / a]
			Eastern Asia		
pop. pot.fed with treated ww	42.750.217,72	[p]		72.405.543,07	[p]
	3,16	% of people pot. fed		5,36	% of people pot. fed
which animal is most suitable to feed humanity			***which animal is most suitable to feed humanity***		
all animals fed with	**Rice, paddy**				
	Chicken			**Duck**	
meat	4.459,84	[kcal/head]		38.245,33	[kcal/head]
	245,52	[heads /p / a]		28,63	[heads /p / a]
	0,139	[m³/head animal feed water / a]		0,256	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		382.453,33	[kcal food for 1 head]
	10,50	[m³ irr. water/head animal food]		90,08	[m³ irr. water/head animal food]
	10,642	[m³/head total]		90,331	[m³/head total]
	2.612,95	[m³ irr, water / p / a]		2.586,25	[m³ irr, water / p / a]
	4.233.672.839,00	[head/a]		601.850.419,00	[head/a]
	586.566.551,69	[m³ feed water / a]		153.772.782,05	[m³ feed water / a]
	45.056.115.144,13	[m³ irrigation water / a]		54.365.490.190,13	[m³ irrigation water / a]
	45.642.681.695,82	[m³ water demand livestock total / a]		54.519.262.972,19	[m³ water demand livestock total / a]

Eastern Asia			
Wheat			
	26.973.740,00	[ha]	
	131,24	[mm / a] | [l/m² / a]	
	1.312.437,50	[l/ha / a]	
	1.312,44	[m³/ha / a]	
Wheat	35.401.347.891,25	[m³/a]	
	185.175.277.920,08	[m³/a]	
	11.025.000.000,00	[m³/a]	
	31,14	% ww of irr. demand from ww	
	8.400.400,02	[ha]	
Wheat	359,00	[kcal / 100g]	
	3.590.000,00	[kcal/ton]	
	4.895.563,33	[kcal/ha]	
	0,0002681	[m³ irr. / kcal]	
		[kcal/p/a]	
	4,47	[p/ha]	
	0,22	[ha/p]	
which crop is most suitable to feed humanity			
Wheat	293,56	[m³ irr. water /p / a]	
	37.556.794,81	[p]	
	2,78	% of people pot. fed	
which animal is most suitable to feed humanity			
	Pig		
	83.765,50	[kcal/head]	
	13,07	[heads /p / a]	
	3,346	[m³/head animal feed water / a]	
	837.655,00	[kcal food for 1 head]	
	197,28	[m³ irr. water/head animal food]	
	200,630	[m³/head total]	
	2.622,67	[m³ irr, water / p / a]	
	444.388.844,00	[head/a]	
	1.486.851.007,22	[m³ feed water / a]	
	89.157.552.412,47	[m³ irrigation water / a]	total m3 / a
	90.644.403.419,69	[m³ water demand livestock total / a]	190.806.348.087,70

Southern Asia		Winners			Livestock	Winners	
1	Rice, paddy	59.347.923	ha/a		Chicken	139	l/a/head
2	Wheat	44.782.524	ha/a		Cattle	14.418	l/a/head
3	Millet	13.017.803	ha/a		Goat	3.699	l/a/head
population		1.441.140.251	people				
prod mun WW		1.927.913.889	m3/a				
Treated mun ww		790.000.000	m3/a				

Southern Asia	Rice, paddy planting date	[mm] actual irrigation requirement	Wheat planting date	[mm] actual irrigation requirement	Millet planting date	[mm] actual irrigation requirement
Afghanistan	1.4.	613,1	1.1.	96,2	1.1.	27,3
Bangladesh	1.4.	-238,6	1.1.	209,9	1.1.	170,3
India	1.4.	565,2	1.1.	554,4	1.1.	380,9
Iran (Islamic Republic of)	1.4.	1107,8	1.1.	394,7	1.1.	238,5
Nepal	1.4.	-278,6	1.1.	38,5	1.1.	77,2
Pakistan	1.4.	1061,4	1.1.	399,3	1.1.	231,6
total		836,9		282,2		187,6

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Rice, paddy	496.667.930.606,25	Wheat	126.360.111.261,00	Millet	24.425.737.695,67	647.453.779.562,92

waste water potential	Southern Asia	
crop irrigation	0,00	
livestock	0,00	
total	0,00	

Southern Asia			Southern Asia		
Rice, paddy			**Wheat**		
harvested area	59.347.923,00	[ha]		44.782.524,00	[ha]
cropwat result (avg. mm irr. demand)	836,88	[mm / a] | [l/m² / a]		282,16	[mm / a] | [l/m² / a]
	8.368.750,00	[l/ha / a]		2.821.638,89	[l/ha / a]
	8.368,75	[m³/ha / a]		2.821,64	[m³/ha / a]
Rice, paddy	496.667.930.606,25	[m³/a]	**Wheat**	126.360.111.261,00	[m³/a]
tot irr dem for 3 main crops / a	647.453.779.562,92	[m³/a]		647.453.779.562,92	[m³/a]
treated ww in region	790.000.000,00	[m³/a]		790.000.000,00	[m³/a]
	0,16	% ww of irr. demand from ww		0,63	% ww of irr. demand from ww
ha crops irr. with treated ww	94.398,81	[ha]		279.979,13	[ha]
Rice, paddy	364,00	[kcal / 100g]	Wheat	364,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.640.000,00	[kcal/ton]
	11.963.466,67	[kcal/ha]		11.329.500,00	[kcal/ha]
	0,0006995	[m³ irr. / kcal]		0,0002491	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,93	[p/ha]		10,35	[p/ha]
	0,09	[ha/p]		0,10	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Rice, paddy	765,98	[m³ irr. water /p / a]	Wheat Southern Asia	272,71	[m³ irr. water /p / a]
pop. pot.fed with treated ww	1.031.357,95	[p]		2.896.825,16	[p]
	0,07	% of people pot. fed		0,20	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Rice, paddy**				
	Chicken			**Cattle**	
meat	4.459,84	[kcal/head]		847.973,25	[kcal/head]
	245,52	[heads /p / a]		1,29	[heads /p / a]
	0,139	[m³/head animal feed water / a]		14,418	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		8.479.732,50	[kcal food for 1 head]
	31,20	[m³ irr. water/head animal food]		5.931,79	[m³ irr. water/head animal food]
	31,336	[m³/head total]		5.946,207	[m³/head total]
	7.693,82	[m³ irr, water / p / a]		7.678,42	[m³ irr, water / p / a]
	1.405.696.548,00	[head/a]		263.821.248,00	[head/a]
	194.756.328,19	[m³ feed water / a]		3.803.642.843,04	[m³ feed water / a]
	44.049.280.900,40	[m³ irrigation water / a]		1.568.735.650.219,87	[m³ irrigation water / a]
	44.244.037.228,59	[m³ water demand livestock total / a]		1.572.539.293.062,91	[m³ water demand livestock total / a]

Southern Asia			
Millet			
	13.017.803,00	[ha]	
	187,63	[mm / a] | [l/m² / a]	
	1.876.333,33	[l/ha / a]	
	1.876,33	[m³/ha / a]	
Millet	24.425.737.695,67	[m³/a]	
	647.453.779.562,92	[m³/a]	
	790.000.000,00	[m³/a]	
	3,23	% ww of irr. demand from ww	
	421.033,93	[ha]	
Millet	378,00	[kcal / 100g]	
	3.780.000,00	[kcal/ton]	
	2.835.000,00	[kcal/ha]	
	0,0006618	[m³ irr. / kcal]	
		[kcal/p/a]	
	2,59	[p/ha]	
	0,39	[ha/p]	
which crop is most suitable to feed humanity			
Millet	724,72	[m³ irr. water /p / a]	
	1.090.074,15	[p]	
	0,08	% of people pot. fed	
which animal is most suitable to feed humanity			
	Goat		
	75.000,00	[kcal/head]	
	14,60	[heads /p / a]	
	3,699	[m³/head animal feed water / a]	
	750.000,00	[kcal food for 1 head]	
	524,64	[m³ irr. water/head animal food]	
	528,343	[m³/head total]	
	7.713,80	[m³ irr, water / p / a]	
	252.347.823,00	[head/a]	
	933.350.481,34	[m³ feed water / a]	
	133.326.153.247,41	[m³ irrigation water / a]	total m3 / a
	134.259.503.728,74	[m³ water demand livestock total / a]	1.751.042.834.020,25

South Eastern Asia				Livestock	Winners	
1	Rice, paddy	43.319.795	ha/a	Chicken	139	l/a/head
2	Maize	9.015.340	ha/a	Duck	256	l/a/head
3	Sorghum	242.518	ha/a	Sheep	2.613	l/a/head
population		505.562.360	people			
prod mun WW		2.627.642.857	m3/a			
Treated mun ww		556.500.000	m3/a			

South Eastern Asia	Rice, paddy planting date	[mm] actual irrigation requirement	Maize planting date	[mm] actual irrigation requirement	Sorghum planting date	[mm] actual irrigation requirement
Cambodia	1.7.	-521,2	1.5.	11,2	1.9.	113,3
Myanmar	1.7.	-56,2	1.5.	98,9	1.9.	126,2
Philippines	1.7.	-154,0	1.5.	13,0	1.9.	0,0
Singapore	1.7.	-236,5	1.5.	11,1	1.9.	0,0
Thailand	1.7.	-113,7	1.5.	116,1	1.9.	172,6
Viet Nam	1.7.	-195	1.5.	131,2	1.9.	0,0
total		0,0		63,6		137,4

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Rice, paddy	0,00	Maize	5.732.253.683,33	Sorghum	333.098.473,00	6.065.352.156,33

waste water potential	South Eastern Asia	
crop irrigation	0,09	
livestock	0,60	
total	0,08	

South Eastern Asia			*South Eastern Asia*		
Rice, paddy			**Maize**		
harvested area	43.319.795,00	[ha]		9.015.340,00	[ha]
cropwat result (avg. mm irr. demand)	-	[mm / a] | [l/m² / a]		63,58	[mm / a] | [l/m² / a]
	-	[l/ha / a]		635.833,33	[l/ha / a]
	-	[m³/ha / a]		635,83	[m³/ha / a]
Rice, paddy	0,00	[m³/a]	**Maize**	5.732.253.683,33	[m³/a]
tot irr dem for 3 main crops / a	6.065.352.156,33	[m³/a]		6.065.352.156,33	[m³/a]
treated ww in region	556.500.000,00	[m³/a]		556.500.000,00	[m³/a]
	#DIV/0!	% ww of irr. demand from ww		9,71	% ww of irr. demand from ww
ha crops irr. with treated ww	#DIV/0!	[ha]		875.229,36	[ha]
Rice, paddy	364,00	[kcal / 100g]	Maize	363,50	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.635.000,00	[kcal/ton]
	11.963.466,67	[kcal/ha]		13.590.356,25	[kcal/ha]
	-	[m³ irr. / kcal]		0,0000468	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,93	[p/ha]		12,41	[p/ha]
	0,09	[ha/p]		0,08	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Rice, paddy	-	[m³ irr. water /p / a]	Maize	51,23	[m³ irr. water /p / a]
			South Eastern Asia		
pop. pot.fed with treated ww	#DIV/0!	[p]		10.862.720,34	[p]
	#DIV/0!	% of people pot. fed		2,15	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Rice, paddy**				
	Chicken			**Duck**	
meat	4.459,84	[kcal/head]		38.245,33	[kcal/head]
	245,52	[heads /p / a]		28,63	[heads /p / a]
	0,139	[m³/head animal feed water / a]		0,256	[m³/head animal feed water / a]
	44.598,40	[kcal food for 1 head]		382.453,33	[kcal food for 1 head]
	-	[m³ irr. water/head animal food]		-	[m³ irr. water/head animal food]
	0,139	[m³/head total]		0,256	[m³/head total]
	34,02	[m³ irr, water / p / a]		7,32	[m³ irr, water / p / a]
	1.935.210.000,00			147.236.323,00	
	268.119.313,81	[m³ feed water / a]		37.618.880,53	[m³ feed water / a]
	268.119.313,81	[m³ irrigation water / a]		37.618.880,53	[m³ irrigation water / a]
	536.238.627,63	[m³ water demand livestock total / a]		75.237.761,05	[m³ water demand livestock total / a]

South Eastern Asia			
Sorghum			
	242.518,00	[ha]	
	137,35	[mm / a] | [l/m² / a]	
	1.373.500,00	[l/ha / a]	
	1.373,50	[m³/ha / a]	
Sorghum	333.098.473,00	[m³/a]	
	6.065.352.156,33	[m³/a]	
	556.500.000,00	[m³/a]	
	167,07	% ww of irr. demand from ww	
	405.169,28	[ha]	
Sorghum	359,00	[kcal / 100g]	
	3.590.000,00	[kcal/ton]	
	4.895.563,33	[kcal/ha]	
	0,0002806	[m³ irr. / kcal]	
		[kcal/p/a]	
	4,47	[p/ha]	
	0,22	[ha/p]	
which crop is most suitable to feed humanity			
Sorghum	307,21	[m³ irr. water /p / a]	
	1.811.444,61	[p]	
	0,36	% of people pot. fed	
which animal is most suitable to feed humanity			
	Sheep		
	178.568,73	[kcal/head]	
	6,13	[heads /p / a]	
	2,613	[m³/head animal feed water / a]	
	1.785.687,30	[kcal food for 1 head]	
	-	[m³ irr. water/head animal food]	
	2,613	[m³/head total]	
	16,03	[m³ irr, water / p / a]	
	59.265.887,00		
	154.885.469,09	[m³ feed water / a]	
	154.885.469,09	[m³ irrigation water / a]	total m3 / a
	309.770.938,17	[m³ water demand livestock total / a]	921.247.326,85

Australia & New Zealand		Winners			Livestock	Winners	
1	Wheat	11.298.852	ha/a		Sheep	2.613	l/a/head
2	Barley	3.645.228	ha/a		Chicken	139	l/a/head
3	Oats	948.049	ha/a		Cattle	14.418	l/a/head
population		24.051.253	people				
prod mun WW		1.821.000.000	m3/a				
Treated mun ww		1.086.750.000	m3/a				

Australia & New Zealand	Wheat planting date	[mm] actual irrigation requirement	Barley planting date	[mm] actual irrigation requirement	Oats planting date	[mm] actual irrigation requirement
Australia	1.4.	211,9	1.4.	231,1		n/a - cropwat
New Zealand	1.4.	0,45	1.4.	0,8		n/a - cropwat
total		106,2		115,9		

water demad	[m3/a]		[m3/a]		[m3/a]	total m3/a
Wheat	11.997.685.996,20	Barley	4.225.912.820,40	Oats	0,00	16.223.598.816,60

waste water potential	Australia & New Zealand	
crop irrigation	0,07	
livestock	0,02	
total	0,02	

Australia & New Zealand			*Australia & New Zealand*		
Wheat			**Barley**		
harvested area	11.298.852,00	[ha]		3.645.228,00	[ha]
cropwat result (avg. mm irr. demand)	106,19	[mm / a] | [l/m² / a]		115,93	[mm / a] | [l/m² / a]
	1.061.850,00	[l/ha / a]		1.159.300,00	[l/ha / a]
	1.061,85	[m³/ha / a]		1.159,30	[m³/ha / a]
Wheat	11.997.685.996,20	[m³/a]	**Barley**	4.225.912.820,40	[m³/a]
tot irr dem for 3 main crops / a	16.223.598.816,60	[m³/a]		16.223.598.816,60	[m³/a]
treated ww in region	1.086.750.000,00	[m³/a]		1.086.750.000,00	[m³/a]
	9,06	% ww of irr. demand from ww		25,72	% ww of irr. demand from ww
ha crops irr. with treated ww	1.023.449,64	[ha]		937.419,13	[ha]
Wheat	364,00	[kcal / 100g]	Barley	336,00	[kcal / 100g]
	3.640.000,00	[kcal/ton]		3.360.000,00	[kcal/ton]
	11.329.500,00	[kcal/ha]		8.433.600,00	[kcal/ha]
	0,0000937	[m³ irr. / kcal]		0,0001375	[m³ irr. / kcal]
	1.095.000,00	[kcal/p/a]			[kcal/p/a]
	10,35	[p/ha]		7,70	[p/ha]
	0,10	[ha/p]		0,13	[ha/p]
which crop is most suitable to feed humanity			*which crop is most suitable to feed humanity*		
Wheat	102,63	[m³ irr. water / p / a]	Barley	150,52	[m³ irr. water / p / a]
pop. pot fed with treated ww	10.589.198,81	[p]		7.219.925,11	[p]
	44,03	% of people pot. fed		30,02	% of people pot. fed
which animal is most suitable to feed humanity			*which animal is most suitable to feed humanity*		
all animals fed with	**Wheat**	Australia & New Zealand			
	Sheep			**Chicken**	
meat	178.568,73	[kcal/head]		4.459,84	[kcal/head]
	6,13	[heads / p / a]		245,52	[heads / p / a]
	2,613	[m³/head animal feed water / a]		0,139	[m³/head animal feed water / a]
	1.785.687,30	[kcal food for 1 head]		44.598,40	[kcal food for 1 head]
	167,36	[m³ irr. water/head animal food]		4,18	[m³ irr. water/head animal food]
	169,976	[m³/head total]		4,319	[m³/head total]
	1.042,31	[m³ irr, water / p / a]		1.060,30	[m³ irr, water / p / a]
	150.373.294,00	[head/a]		96.607.484,00	[head/a]
	392.985.566,54	[m³ feed water / a]		13.384.765,64	[m³ feed water / a]
	25.559.817.610,92	[m³ irrigation water / a]		417.199.794,09	[m³ irrigation water / a]
	25.952.803.177,46	[m³ water demand livestock total / a]		430.584.559,74	[m³ water demand livestock total / a]

Australia & New Zealand		
Oats		
	948.049,00	[ha]
	-	[mm / a] | [l/m² / a]
	-	[l/ha / a]
	-	[m³/ha / a]
Oats	0,00	[m³/a]
	16.223.598.816,60	[m³/a]
	1.086.750.000,00	[m³/a]
	#DIV/0!	% ww of irr. demand from ww
	#DIV/0!	[ha]
Oats	404,00	[kcal / 100g]
	4.040.000,00	[kcal/ton]
	14.746.000,00	[kcal/ha]
	-	[m³ irr. / kcal]
		[kcal/p/a]
	13,47	[p/ha]
	0,07	[ha/p]
which crop is most suitable to feed humanity		
Oats	-	[m³ irr. water /p / a]
	#DIV/0!	[p]
	#DIV/0!	% of people pot. fed
which animal is most suitable to feed humanity		
	Cattle	
	847.973,25	[kcal/head]
	1,29	[heads /p / a]
	14,418	[m³/head animal feed water / a]
	8.479.732,50	[kcal food for 1 head]
	794,76	[m³ irr. water/head animal food]
	809,175	[m³/head total]
	1.044,90	[m³ irr, water / p / a]
	35.603.257,00	[head/a]
	513.309.957,80	[m³ feed water / a]
	28.809.261.896,96	[m³ irrigation water / a]
	29.322.571.854,76	[m³ water demand livestock total / a]

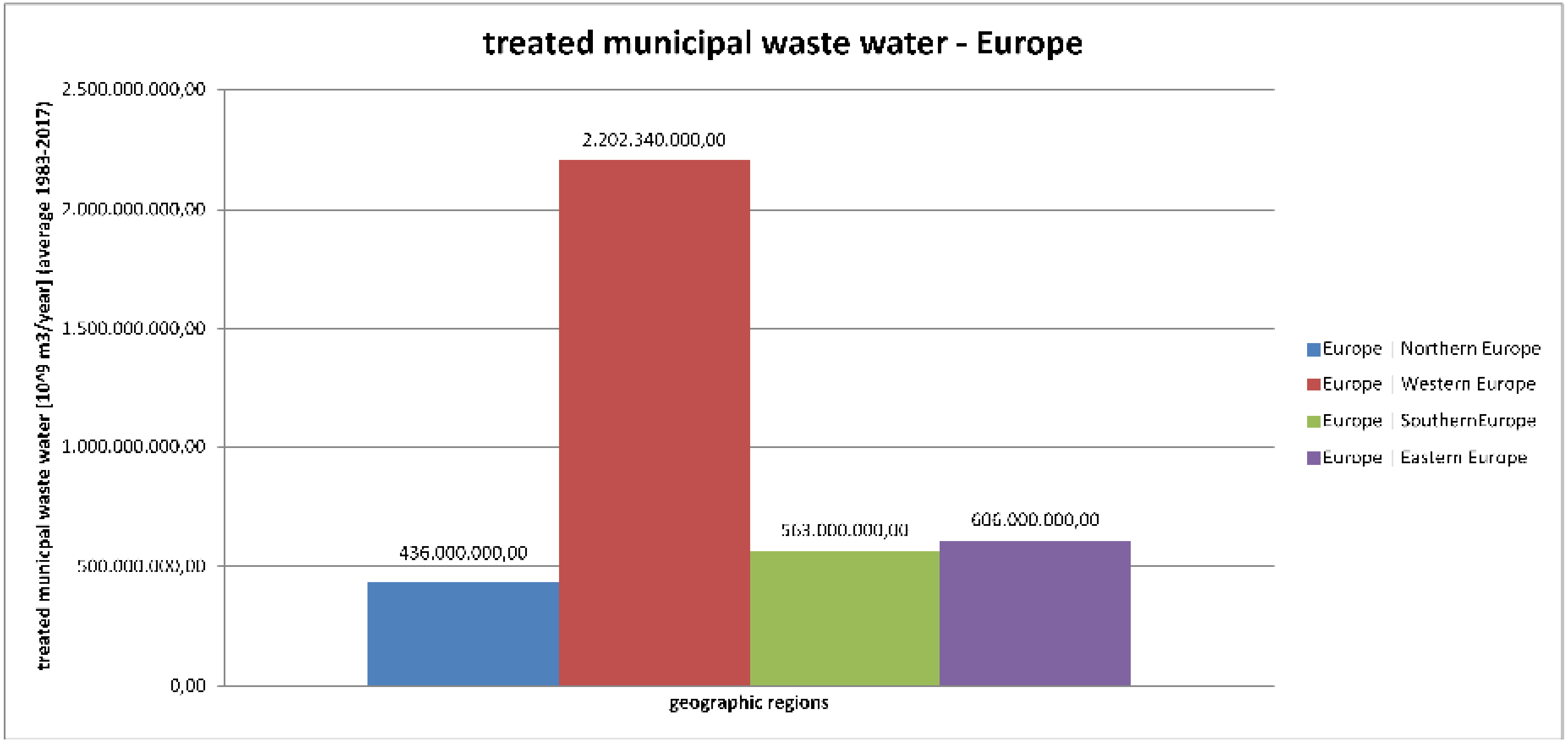
total m3 / a
55.705.959.591,95

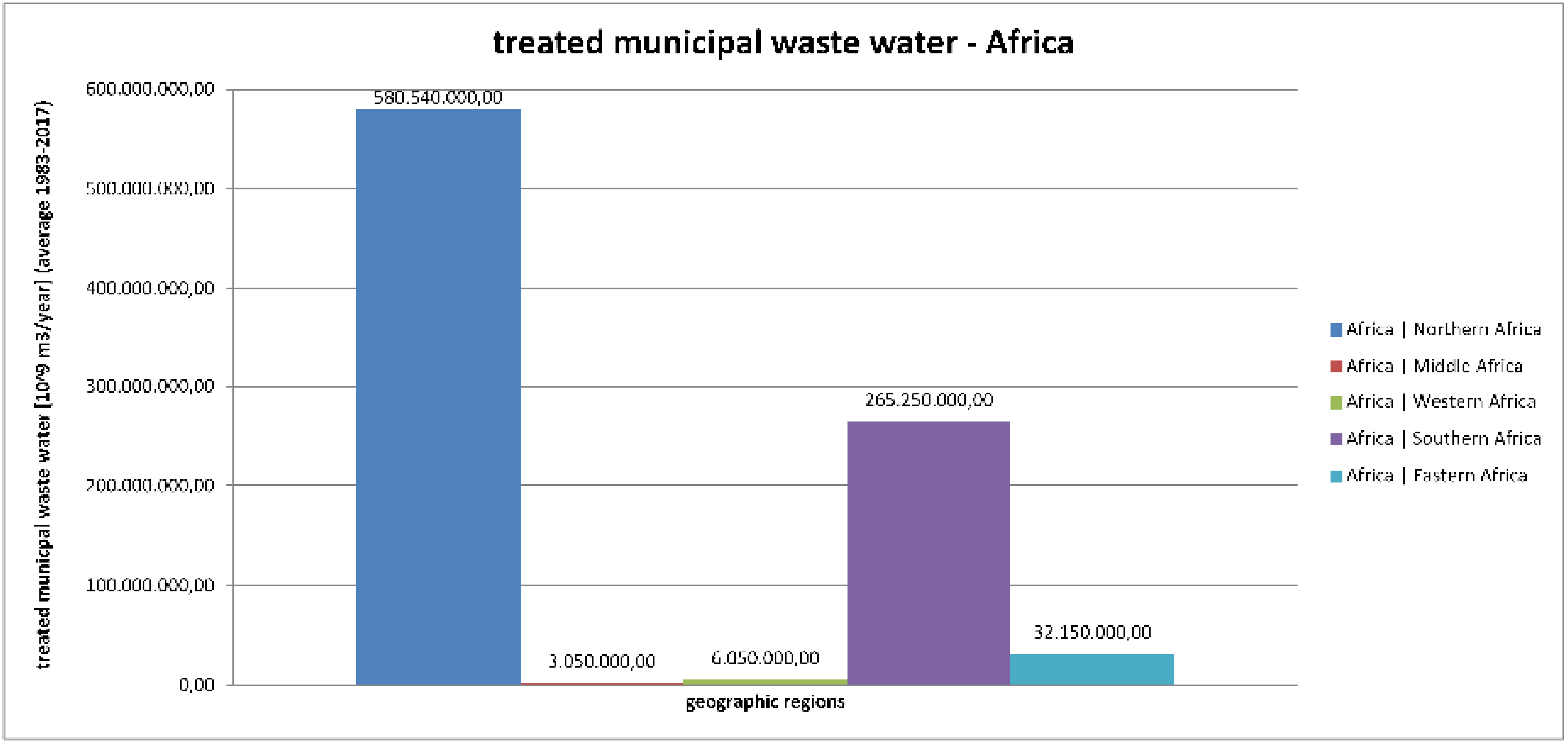
Nutrition Equivalent									
https://www.nutritionvalue.org/Duck%2C_raw%2C_meat_and_skin%2C_domesticated_nutritional_value.html - accessed 17.04.2019									
[100g]	[kcal]	[g]	[kcal/ton]	[g/ton]		[kcal/head]	[g/head]	[kcal/l]	[g/l]
Meats	kcal/100g	protein/100g	kcal/ton	proten/ton		kcal/head	protein/head	footprint	footprint
Duck, Domestic	404	11	404.000.000,000	11.000.000,000		38.245,33	1.041,33	149,69	4,08
https://ndb.nal.usda.gov/ndb/nutrients/index - accessed 17.04.2019									
Beef	219,54	25,25	219.540.000,000	25.250.000,000		847.973,25	975.281,25	58,82	67,65
Pork	184,1	23,2	184.100.000,000	23.200.000,000		83.765,50	105.560,00	25,04	31,55
Chicken	231,68	21,92	231.680.000,000	21.920.000,000		4.459,84	4.219,60	32,19	30,46
Turkey	175	26,95	175.000.000,000	26.950.000,000		10.456,25	16.102,63	59,60	91,78
Sheep/lamb	235,89	22,49	235.890.000,000	22.490.000,000		178.568,73	170.249,30	68,33	65,14
[100g]	[kcal]	[g]	[kcal/ton]	[prot/ton]		[kcal/ha]	[g/ha]	[p/ha]	[ha/p]
Plants	cal/100g	protein/100g	kcal/ton	proten/ton		kcal/ha	protein/ha		
Barley	345	10,5	3.450.000,000	10.500.000,000		8.006.156,25	24.366.562,50	7,31	0,14
Maize/Corn	363,5	8,77	3.635.000,000	8.770.000,000		13.590.356,25	32.788.837,50	12,41	0,08
Oats	404	14,66	4.040.000,000	14.660.000,000		14.746.000,00	53.509.000,00	13,47	0,07
Rice	364	7,18	3.640.000,000	7.180.000,000		11.963.466,67	23.598.266,67	10,93	0,09
Sorghum	359	8,43	3.590.000,000	8.430.000,000		4.895.563,33	11.495.710,00	4,47	0,22
Wheat	364	10,33	3.640.000,000	10.330.000,000		11.329.500,00	32.152.125,00	10,35	0,10
Triticale	336	13	3.360.000,000	13.000.000,000		8.433.600,00	32.630.000,00	7,70	0,13
Millet	378	11	3.780.000,000	11.000.000,000		2.835.000,00	8.250.000,00	2,59	0,39
Goat	150	19,5	1.500.000,000	19.500.000,000		75.000,00	64.090.000,00	20,28	0,05

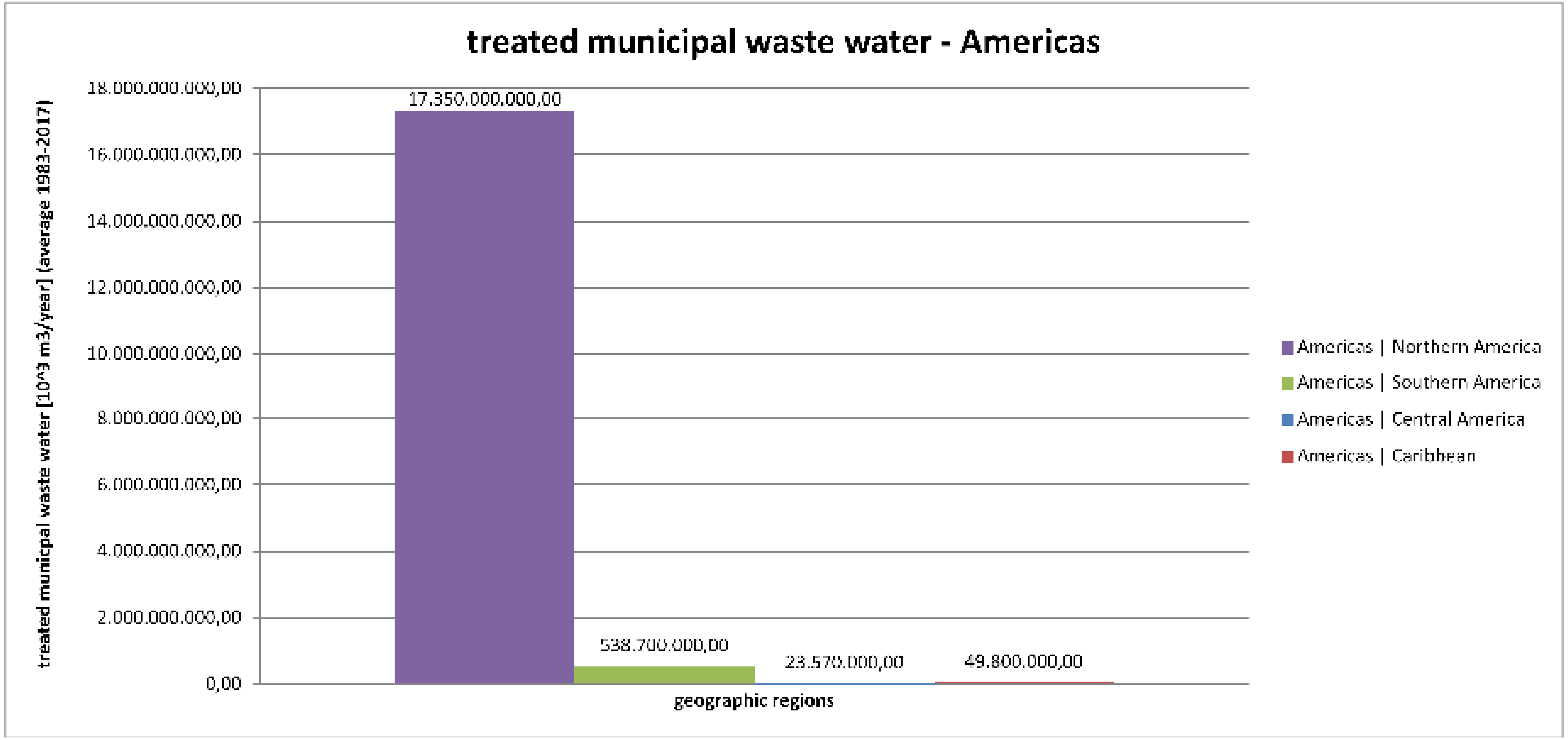
feedwater requirements			
	weigth range [kg]	Average Typical Water Useb [L/day]	Average Typical Water Use [L/a]
Beef Cattle Type	*http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#7*		
Feedlot cattle: Backgrounder	181-364	24	8.760,0
Feedlot cattle: Short keep	364-636	41	14.965,0
Lactating cows with calves	-	55	20.075,0
Dry cows, bred heifers & bulls	-	38	13.870,0
average		39,5	14.418
Swine Type	*http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#7*		
Weaner	7-22	2	730,0
Feeder pig	23-36	4,5	1.642,5
Feeder pig	36-70	4,5	1.642,5
Feeder pig	70-110	9	3.285,0
Gestating sow/boar	-	15	5.475,0
lactating sow	-	20	7.300,0
average		9,2	3.346
Sheep Type	*http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm#7*		
Feeder lamb	27-50	4,4	1.606,0
Gestating meat ewe/ram	80	5,25	1.916,3
Lactating meat ewe plus calf	80+	10	3.650,0
Gestating dairy ewe/ram	90	5,75	2.098,8
Lactating dairy ewe	90	10,4	3.796,0
average		7,2	2.613
Goat Type	*https://www.ontariogoat.ca/wp-content/uploads/2015/12/OG-Gazette-6-Water-FINAL-2015-12.pdf*		
doe / buck	50	9,5	3.467,5
kids	-	7,7	2.810,5
Lactating doe	-	13,2	4.818,0
average		10,1	3.699

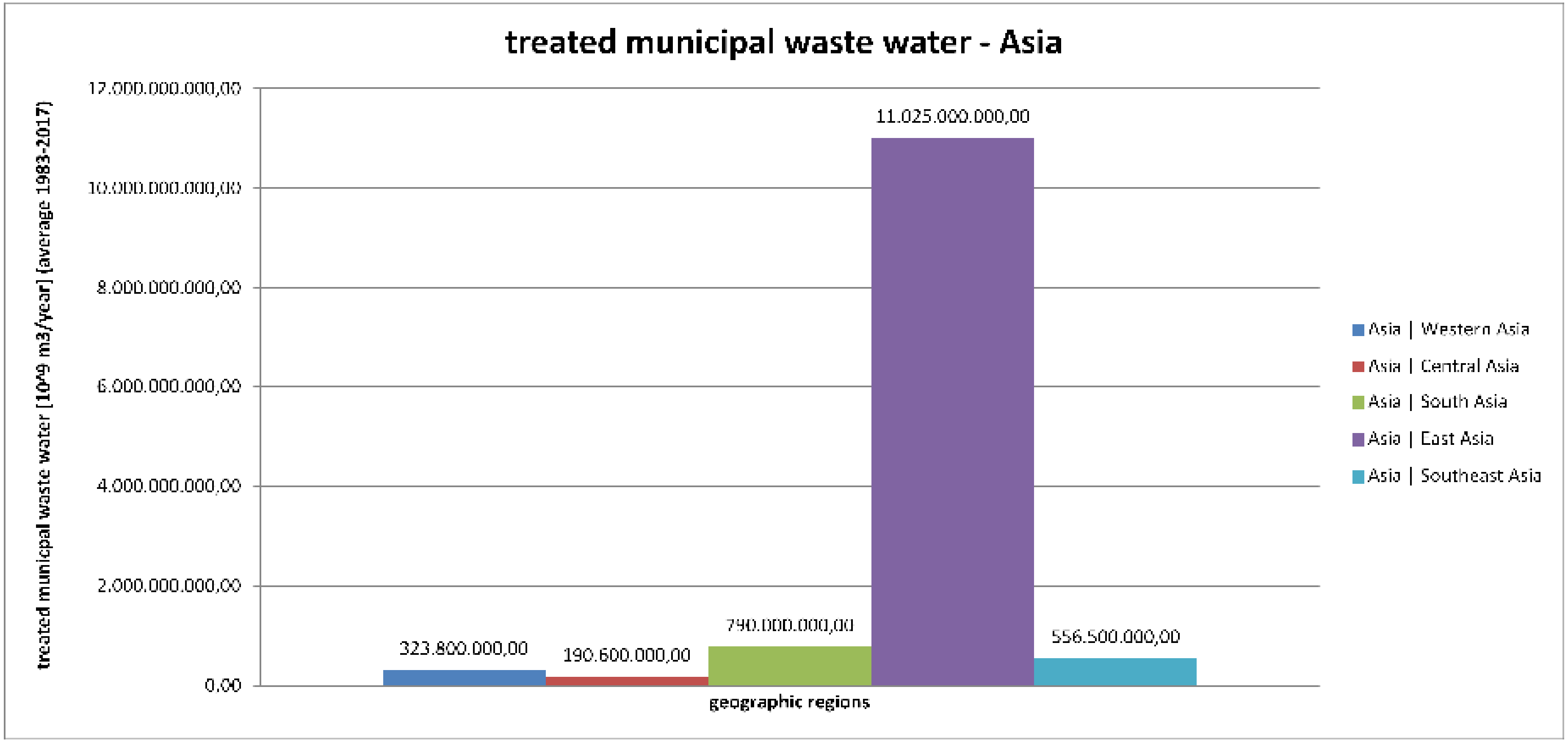
			10°C-21°C		27°C-35°C	Total annual consumption [L/a]
Turkey Type	*http://www.omafra.*	Fall/Winter/Spring [L/day]	Fall/Winter/Spring [L/a]	Summer [L/day]	Summer [L/a]	W&S
Broilder Turkey	-	0,296	63,0	0,4	61,1	124,2
Heavy hens	-	0,431	91,8	0,6	91,3	183,0
Turkey toms	-	0,513	109,2	0,7	110,0	219,2
average		0,4	88,0	0,6	87,4	175
			10°C-21°C		27°C-35°C	Total annual consumption [L/a]
Chicken Type	*http://www.omafra.*	Fall/Winter/Spring [L/day]	Fall/Winter/Spring [L/a]	Summer [L/day]	Summer [L/a]	W&S
Broiler Chicken	-	0,28	59,6	0,5	68,4	
Laying hens	1,6-1,9	0,25	91,3	-	-	
Pullets	0,05-1,5	0,105	38,3	-	-	
Broiler breeders	3-3,5	0,25	91,3	-	-	
average		0,2	70,1	0,5	68,4	139
Duck Type	*Water consumption for livestock and poultry production, January 2003, Publisher: Marcel DekkerEditors: B.S. Stewart, T. A. Howell*					
White Pekin (4h H2O access)	-	0,6	219,0			
White Pekin (24h H2O access)	-	0,8	292,0			
average		0,7	256			

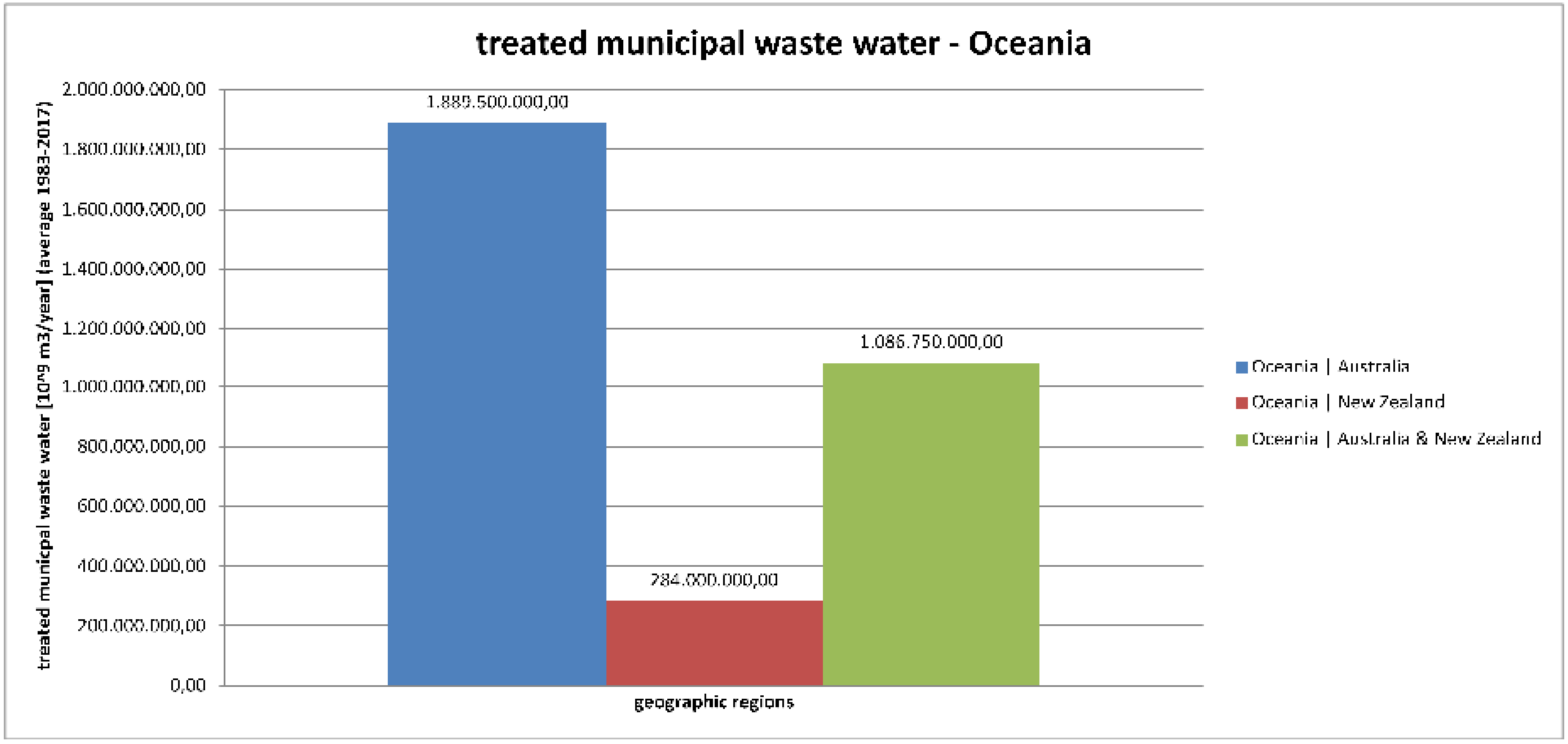
Annex 2: Waste water output results




treated municipal waste water - Africa
treated municipal waste water [10^9 m3/year] (average 1983-2017)
600.000.000,00
500.000.000,00
400.000.000,00
300.000.000,00
200.000.000,00
100.000.000,00
0,00
580.540.000,00
3.050.000,00
6.050.000,00
265.250.000,00
32.150.000,00
geographic regions
Africa | Northern Africa
Africa | Middle Africa
Africa | Western Africa
Africa | Southern Africa
Africa | Eastern Africa


treated municipal waste water - Americas
treated municipal waste water [10^3 m3/year] (average 1983-2017)
18.000.000.000,00
16.000.000.000,00
14.000.000.000,00
12.000.000.000,00
10.000.000.000,00
8.000.000.000,00
6.000.000.000,00
4.000.000.000,00
2.000.000.000,00
0,00
17.350.000.000,00
538.700.000,00
23.570.000,00
49.800.000,00
geographic regions
Americas | Northern America
Americas | Southern America
Americas | Central America
Americas | Caribbean


treated municipal waste water - Asia
treated municipal waste water [10^9 m3/year] (average 1983-2017)
17.000.000.000,00
10.000.000.000,00
8.000.000.000,00
6.000.000.000,00
4.000.000.000,00
2.000.000.000,00
0,00
323.800.000,00
190.600.000,00
790.000.000,00
11.025.000.000,00
556.500.000,00
geographic regions
Asia | Western Asia
Asia | Central Asia
Asia | South Asia
Asia | East Asia
Asia | Southeast Asia


treated municipal waste water - Oceania
treated municipal waste water [10^9 m3/year] (average 1983-2017)
2.000.000.000,00
1.800.000.000,00
1.600.000.000,00
1.400.000.000,00
1.200.000.000,00
1.000.000.000,00
800.000.000,00
600.000.000,00
400.000.000,00
200.000.000,00
0,00
1.889.500.000,00
284.000.000,00
1.086.750.000,00
geographic regions
Oceania | Australia
Oceania | New Zealand
Oceania | Australia & New Zealand