

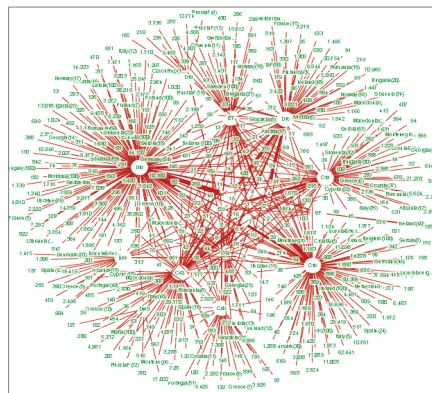
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Applying the New Science of Networks to Planetary Agriculture

Volume I



The Impact of Climate Change and Demography on Food Availability up to 2100





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Food for every human on the planet Earth – 2100

The approach of Science of Network to address this problem is innovative, as well as the introduction of the Köppen-Geiger Climate Classification System.

The research and the formulated recommendations in this work, represent a worth-full endeavor for progressing in solving the intolerable -present and future- hunger »problématique«. Let this publication »*Applying the New Science of Networks to Planetary Agriculture*« be a case of success.

Prof. Dr. Timi Ecimovic

Executive Summary

Agriculture is born with the emergence of the human species on the planet earth. Food is critical to the survival for the living societies and evidently for their civilizations. Therefore enough food for all is a sustainable issue per excellence. The collapse of societies has been commented in the literature extensively and has illustrated the importance of geographical locations and the impact of the human behavior on the environment.

*This report gives an overview of work in progress of the application of the **New Science of Networks** applied to agriculture at terrestrial planetary scale and the impact of **demography** and **Climate Change** during this century. It is an attempt of looking on earth's evolution in the present century of the world food 'problématique' and with the help of existing publications and comments, to reach an holistic synthesis about one of the most vital challenges humankind is facing.*

*The research project make use of the Climate Classification system from **Wladimir Köppen** and **Rudolf Geiger**. This climate system is widely used and has been regularly updated with satellite observations of the last decades. It has the considerable advantage to address climate phenomena independently from national borders and countries. This approach is distinct from usually defined borders based on juristic defined and recognized identities, applied by international organizations. Linkage between countries and continents and the Climate Zones as defined by the Köppen-Geiger system does exists and allows to combine Climate Zones with countries and their available data provided by United Nations institutions, such FAO and ECOSOC.*

*The **demographic increase** of the 21st century, requires to look in a different way to the significance of agriculture for the survival of the human species. Demographic data are taken from UN ECOSOC Population Division and cover the period from 1950 up to 2300 for the different continents. In this report a time limit is chosen at 2100, for the population*

curves show at that point an endpoint in planetary demographic increase and evolves to a plateau or even decline.

*The **New Sciences of Networks and Complexity** emerged some decades ago. As far as the authors know, they have not been explored yet to agriculture approaching a real existential matter for the human species. Additionally the phenomenon of Climate Change increased the curiosity to look for the application, in particular of the Science Networks. The present approach deliberately is limited to 'physical' parameters of agriculture, in an analogous way of the famous report to the Club of Rome, *The limits to growth* (1972). So no economic data nor trade aspects have been addressed.*

*'Open source' software such as : **Gephi** (The Open Graph Viz Platform) and the program language, **R**, for statistical analyses have been used. Both tools made graphical exploration possible and are inspired by **Graph Theory**. With the help of own programming the following diagrams have been obtained : adjacency radiogram, dendrograms, decision trees and double logarithmic plots. All help to look after correlations among Climate Zones and the agriculture items : crops, meat, arable land and water use.*

In the final chapter some recommendations have been formulated in form of longer term actions to be considered at planetary level. The formulated suggestions to reach food for everybody by the end of the 21st century, are summarized as follows :

- Converting land for meadows & pastures to land for crops; the ratio fluctuates from 8 to 52 depending on the continents.*
- Improve management of water-withdrawal globally and in particular for agriculture, which uses already 75% of the total water-withdrawal. The effects of climate variability, global warming, extreme weather conditions and increased demography added the today's people living with dramatic water scarcity.*
- Increase crops production through generalized breeding, applying endogenous GMO techniques, increasing C4 plants which absorb higher quantities of carbon dioxide and showing better adaptability to changing weather conditions (drought) or eco-environment (salinity).*
- The use of food and feed resources for producing biofuel is considered unsustainable and therefore not recommended. These resources diminish not only the available food for humans, but additionally need arable land and fresh water for their production, all increase the undesired food scarcity.*
- Livestock as provider of meat (proteins) and dairy products increases demand higher water quantities, feed and land. Intensive animal husbandry can reduce land use in form of meadows and pastures land, as is already practiced for some species (pigs and poultry).*

- *The African continent with its strong population increase by a factor 2.83 this century, resulting in 2.1 billion people. Global warming increases desertification and extends the already large deserts (Sahara and Sahel) and enhances the water scarcity as well. Massive investment is recommended for increasing locally and regionally agricultural output. Investment, over several decades, in small scale mechanization of local farmers, but also in capacity building (education) of the population in order to get acquainted with more advanced agricultural practices.*
- *Global governance. Food for everybody is a humanistic objective, not yet reached. Given the additional challenges, demographic increase global warming effects on food output, urge a dramatic but strong and systematic help for the African and some parts of the Asian continents. Enough food is a condition for survival. Missing this objective opens the gate for massive social unrest and political instability. The question is raised if an appropriate world governance body should be set up for dealing with this problem? Food is existential, and getting even more critical than ever before, therefore massive attention and investment have to be envisioned.*

The food “problématique” has been analyzed and commented extensively resulting in thousands of publications.. A considerable effort has been deployed here to have an 'holistic' and an 'innovative' analysis and approach. *Graph Theory* and *Science of Networks*, here introduced, but require further research. Indeed, agriculture and food availability is a huge domain for research, which becomes an existential dimension for the human species.

A second volume of this publication, *Volume II*, is under preparation and will be available by mid-year. This volume will contain all graphical layouts (Gephi) and all the data tables used to obtain them, as well as the results obtained with R.

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Introduction

The emergence of new sciences and knowledge providers, such as the New Sciences of Networks and Complexity, are likely able to provide new approaches to the challenge of agriculture. Their analytical tools look at the inter-linkage of very diverse and large amount of parameters and provide better understanding of the global system, than otherwise experts and scientists could do.

The following scientists/thinkers have largely inspired the authors to get involved in the present analysis. They are :

*Norman Borlaug*¹ received the Nobel Price for Peace in 1970, for his exceptional work of breeding of wheat and has been identified thereafter with the 'green revolution'.

*James Lovelock*² is well known for the elaboration of the Gaia Hypothesis which later became the *Gaia Theory*. His description of the inter-linkage of the lithosphere, the atmosphere and the biosphere is definitely original. His description of the role of the biosphere as the regulator of the earth or Gaia system, enlightens in a unique manner, the vulnerability of the eco- biosphere of humankind's intervention.

*Edward O. Wilson*³ has contributed substantially to the understanding to importance of biodiversity of the earth system. The question formulated, in his book *In search of nature. Is humanity suicidal?*, has marked the thinking about the future of our human species.

*James Hansen*⁴ is best known for his research in the field of climatology and his advocacy of action to avoid dangerous climate change. His scientific work has advanced to understand the challenges humankind is facing as a consequence of the impact of unlimited technological activity, leading to dramatic climate change and climate variability world wide. In recent years, he has become a climate activist for action to mitigate the effects of climate change, the in the meantime legendary testimonies before the Hearing Committee of the US Congress in 1988 and in 2008 exactly twenty years after, are indeed remarkable intellectual statements.

Club of Rome's publication *The limits to growth*⁵ of 1972 had a remarkable impact on the mindset of leaders in the most diverse domains: exact and social sciences, political leaders and NGOs. Two generations and hopefully more to come will have a large inspiration on how to manage our planet. Indeed, humankind misuses in an unbridled way, planetary resources trespassing ecological equilibrium of the planetary system. We have only one planet to live on!

*Global Footprint Network*⁶ organization has inspired the present thinking and concern about the status of the planet, reminding constantly the physical limits of our planet. In case of agriculture, that importing food from other places of the earth for the consumption elsewhere, means the creation of a footprint on the place of production.

Obviously, many other scientists/thinkers have, all along our individual lifetime, lead to the present work.

Agriculture is a huge complex system to which a manifold of parameters determine its ability for servicing humankind as it has done for millenniums. During this long period the demographic evolution of human species has continuously increased and is estimated to reach some ~10 billion people by the end of the 21st century or even before. However, the recent global warming phenomenon modifies dramatically the perspectives for the well being of a numerous human species.

Food for all is already today a cumbersome challenge^{7, 8}. According to UN statistics, about 840 million people are undernourished, which in reality is most likely much higher and an additional quantity of humans of some 2,5 billion individuals will be added by the end of the 21st century. This means that about half of today's human-kind as to be provided with food. This is not the end of the story. The global economic development enhances the consumption of animal food, which requires additional production of fodder by the agriculture system.

The importance of the natural environment, like the availability of arable land, fresh water, stable weather conditions, has been recognized to become critical in the future. All be it, human species could create its own collapse⁹.

Will humanity, with its actual world governance structures, succeed in answering this real vital question, is not yet known? If humankind does not succeed, then obviously major social conflicts will emerge and world wide.

The present approach introduces at least two innovating investigation techniques, namely the introduction of an overarching climate classification system, well known as the *Köppen-Geiger Climate Classification System*¹⁰ (KGCCS) and the recent developed scientific method, known as the *New Science of Networks*. Since about half a century several new knowledge accumulators have emerged as is beautifully pictured in the diagram published by *Brian Castellani & Frederic Hafferty*¹¹ and reproduced in *Wikipedia*.

An overarching climate classification system has a number of advantages, in particular it addresses large regions defined by geographical and geological properties, allowing to trespass legal but frequently arbitrary boundaries, which are used, by definition, by international institutions. Although the KGCC system has its roots in the early 20th century, it has been updated with satellite observation systems, making it a modern tool, with a resolution 0,5 degree grids (latitude/longitude), appropriate for the kind of research of the present investigation.

FAO Statistical material of terrestrial food production -in terms of crops and meat production- are extensively available. These data have been linked, along the following structure, Climate Zones → Continents → Countries, making the use of FAO data, based on countries, possible with climate classification zones. Indeed an additional focus emerged

from the basic data by taking into account the specificity of the continents which show specific differences in geography, demographic growth, cultural evolution quite substantially.

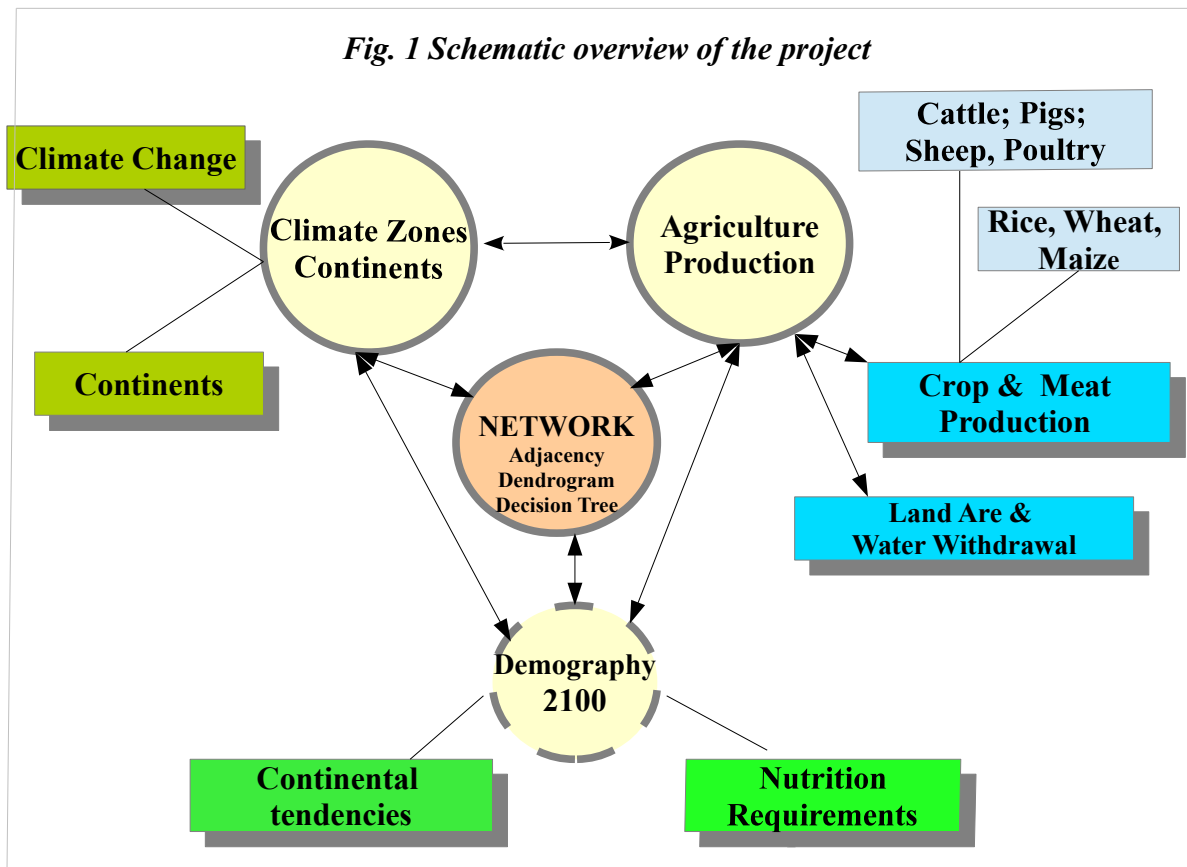
The demographic evolution of the present century are well known, even the UN statistics go beyond this time frame up to 2300. We have chosen to limit this investigation to the year 2100, which corresponds to a maximum, after which some kind of plateau and eventually a systemic decline of the world population could appear.

The fundamental question to be answered is the impact of Climate Change on food production and above all to the increased of food availability by 2100. Temperature and precipitation are accepted to be the main drivers of climate change and global warming. However there are other parameters such as weather variability causing sudden but dramatic reduction of crop harvesting. Also the question of soil erosion, linked to the Climate Zones of the KGCCS, is a domain to be integrated in this approach of investigation.

Our recognition goes also to the *FAO*, *UN* Statistics institutions, without their open access data and publications, it would not have been possible to address this new scientific field of networking.

Chapter 1. The Structure of the Project & Research Building Blocks

Agriculture is a complex system, in which geographical & climate elements as well as cultural & societal, historical, religions and beliefs are of great importance. In Fig.1 is drawn a schematic overview of the present research project : the triangle **Agriculture Production**, the **Climate Zones** related to the impact of global warming and the **Demography**. Large attention is given to **Continents** in order to high-light important differences, in particular, concerning the evolution of their demography. In the center of the diagram is the applied methodology of the **Science Networks** for correlating their mutual interactions. The time scale is projected to cover the present century.



Scarcity of food has occurred all over history of humankind due to a manifold of events, and it is still a fact present day. According to UN-FAO Statistics⁸ for the years 2011-2013 there are still 842 million people suffering malnutrition and/or hunger, representing is about 12% of the entire population.

The application of the *Sciences of Networks*¹² have the potentiality of another approach, not applied before, to throw a better light on the global conditions of food production in this century. These methods allow quantifying the relationships between the three domains and

with the help of scenarios to provide insights, supported by quantitative data and models, where the human species is heading to, and where the most vulnerable places for food output on earth are located.

Of course, it would be desirable to build realistic scenarios for longer periods of time, say beyond two centuries or so, but this seems not really possible, for unpredictable major events will occur. This would lead to totally wrong evaluation of human behavior.

1.1 Applying the Sciences of Networks and Complexity^{13, 14, 15}

Graph theory¹⁶ is the study of points and lines. In particular, it involves the ways in which sets of points, called *vertices*, can be connected by lines or arcs, called *edges*. Graphs in this context differ from the more familiar coordinate plots that portray mathematical relations and functions. Graphs are a tool for modeling relationships. They are used to find answers to a number of problems. The subject of graph theory had its beginnings in recreational math problems, but it has grown into a significant area of mathematical research with a wide variety of applications. The history of graph theory may be specifically traced to 1735, when the Swiss mathematician *Leonhard Euler* solved the *Königsberg Bridge* problem. This problem was an old puzzle concerning the possibility of finding a path over every one of seven bridges that span a forked river.

Networks and Complexity are at the front line of new knowledge acquisition^{17,18} They stress the inter-linkage of elements of a given system. It has been underlined that the world society needs 'holistic' types of knowledge for better understanding its increasingly complex character, these sciences are a step forward in that direction.

Some recent insights, in a large variety of domains, demonstrate the richness of the applicability of these sciences e.g. the structure of the Internet, the metabolism in bacterial cells, social networks, etc. Other domains of application can be envisioned -or are in the mean time explored- to bring new insights : e.g. analysis and search for remediation of the worldwide financial crises; nature and size of social developments in nations with emerging economies; health research and disease dissemination; diminishing of bio-diversity at planetary scale; etc.

In the present research project, implicitly these new approaches have been used. It is a first trial to apply it to a vast planetary dual challenge, spread over a long period of time, namely this century: demography and impact of Climate Change on food production.

1.2 The Köppen-Geiger Climate Classification Systems^{19,20} (KGCCS)

The *Wladimir Köppen* climate classification is a wide used climate classification system. It was first published by Köppen in 1884, with several later modifications himself, notably in 1918 and 1936. Later, the climatologist *Rudolf Geiger* collaborated with *W. Köppen* on

changes to the classification system, which is now referred to as the **Köppen-Geiger Climate Classification System (KGCCS)**.

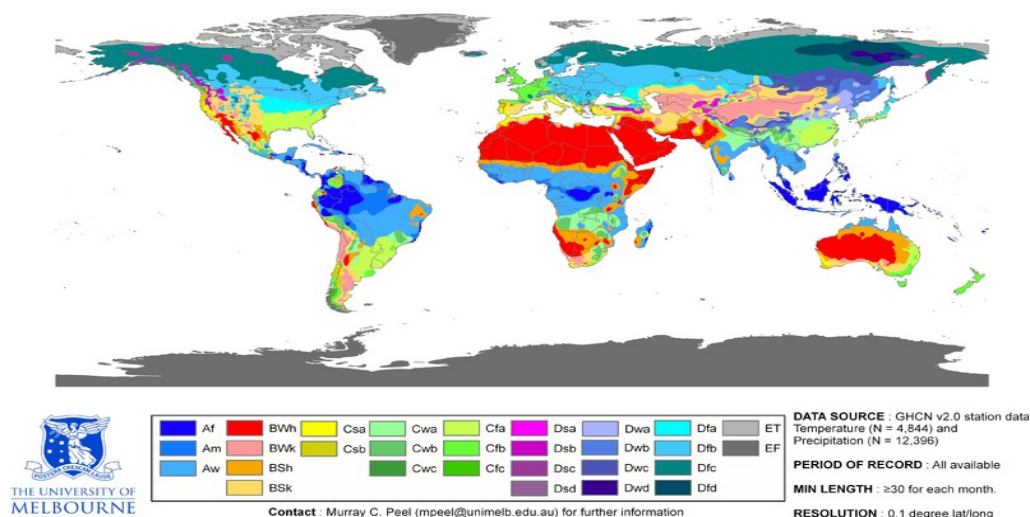
Many researchers routinely use it for their own particular research purposes. *Peel et al*²⁰ have used for a global analysis of precipitation phenomena. *Lohmann et al*²¹ (1993) have applied the Köppen-Geiger classification to the output from both atmosphere general circulation models and coupled atmosphere-ocean circulation models and compared these to maps of the Köppen-Geiger classification using modern data sets and to Köppen's 1923 map²³.

A comprehensive Köppen world map drawn from gridded data to date is that of *Kottek et al*^{23, 24} (2006) who presented a map with 31 climate types at a resolution of 0.5° latitude by 0.5° longitude based on both the CRU (Climate Research Unit, the University of East Anglia), and GPCC (Global Precipitation Climatology Centre, World Meteorological Organization (WMO), operated by the Deutscher Wetterdienst (DWD)) data sets for the period 1951–2000.

The choice of climate zones, rather than countries with legal boundaries, as an overarching system allowing to better correlate or link physical and geographical properties has been for estimating the impact of global warming and climate change and the demographic evolution on agriculture output. Another possibility could have been the soil zones, which would have been certainly quite valuable, however its sensitivity to climate variability and extreme weather conditions looks more uncertain, and therefore, at present, the choice went to climate zones.

Fig 2a Illustration of the Climate Zones

World map of Köppen-Geiger climate classification



- The **snow climate D** has the lowest monthly mean temperature equal or lower than -3°C , whereas the sub-types are decided based on the seasonal precipitation.
- Finally the **polar climate E** has the highest monthly mean temperature equal or lower than $+10^{\circ}\text{C}$, and the two sub-types further divide the major group into two temperature conditions.

According to *Hans Chen*^{25, 26} The Köppen-Geiger Classification System comprises a total of 31 climate zones (CZ) described by a code of *three letters*.

- *First and second letter (Table 1a)*

Tables 1a Structure of Köppen-Geiger Climate Zones

Class	CZ		
A		Tropical/mega-thermal climates	
	Af		Tropical rain forest
	Am		Tropical monsoon
	As		Tropical savannah with dry summer
	Aw		Tropical savannah with dry winter
B		Dry -arid and semi-arid- climates	
	BW		Desert (arid)
	BS		Steppe (semi-arid)
C		Temperate/meso-thermal climates	
	Cs		Mild temperate with dry summer
	Cw		Mild temperate with dry winter
	Cf		Mild temperate, fully humid
D		Continental/micro-thermal Clim.	
	Ds		Snow with dry summer
	Dw		Snow with dry winter
	Df		Snow, fully humid
E		Polar & Alpine climates	
	ET		Tundra
	EF		Frost

- **The Third letter**

The annual mean near-surface (2 m) temperature is denoted by T_{ann} and the monthly mean

temperatures of the warmest and coldest months by $T_{\max}$ and $T_{\min}$, respectively. The temperature classification (h) and (k) for the arid climates (B) and (a) to (d) for the warm temperate and snow climates (C) and (D). Note that for type (b), warm summer, a threshold temperature value of $+10^{\circ}\text{C}$ has to occur for at least four months. *M. Kottek et al*²².

All precipitation variables are in units of millimeters (mm) and all temperature variables are in units of degrees Celsius ($^{\circ}\text{C}$).

- The Temperature parameter

Table 1b Temperature

Type	Description	Criterion
h	Hot steppe / desert	$T_{\text{ann}} \geq +18^{\circ}\text{C}$
k	Cold steppe /desert	$T_{\text{ann}} < +18^{\circ}\text{C}$
a	Hot summer	$T_{\max} \geq +22^{\circ}\text{C}$
b	Warm summer	$T_{\max} < +22^{\circ}\text{C}$, 4 $T_{\text{mon}} \geq +10^{\circ}\text{C}$
c	Cool summer and cold winter	$T_{\max} < +22^{\circ}\text{C}$, 4 $T_{\text{mon}} < +10^{\circ}\text{C}$, $T_{\min} > -38^{\circ}\text{C}$
d	extremely continental	$T_{\max} < +22^{\circ}\text{C}$, 4 $T_{\text{mon}} < +10^{\circ}\text{C}$, $T_{\min} \leq -38^{\circ}\text{C}$

Globally the dominant climate class by land area is arid B (30.2%) followed by cold D (24.6%), tropical A (19.0%), temperate C (13.4%) and polar E (12.8%). The most common individual climate type by land area is BWh (14.2% Hot desert), followed by Aw (11.5% Tropical Savannah).

- The Precipitation parameter

P_{ann} is the accumulated annual precipitation and $P_{\min}$ is the precipitation of the driest month. Additionally P_{smin} , P_{smax} , P_{wmin} and P_{wmax} are defined as the lowest and highest monthly precipitation values for the summer and winter half-years on the hemisphere considered. All temperatures are given in $^{\circ}\text{C}$, monthly precipitations in mm/month and P_{ann} in mm/year.

Table 1c Precipitation

P_{ann}	accumulated annual precipitation
$P_{\min}$	precipitation of the driest month
P_{smin}	lowest monthly precipitation values for the summer half-years
P_{smax}	highest monthly precipitation values for the summer half-years
P_{wmin}	lowest monthly precipitation values for the winter half-years
P_{wmax}	highest monthly precipitation values for the winter half-years

In addition to these temperature and precipitation values, a dryness threshold P_{th} in mm is introduced for the arid climates (B), which depends on $\{T_{ann}\}$, the absolute measure of the annual mean temperature in °C, and on the annual cycle of precipitation:

$$P_{th} = \begin{cases} 2\{T_{ann}\} & \text{if at least 2/3 of the annual precipitation occurs in winter,} \\ \{T_{ann}\}+28 & \text{if at least 2/3 of the annual precipitation occurs in summer,} \\ 2\{T_{ann}\}+14 & \text{otherwise.} \end{cases}$$

The scheme how to determine the additional temperature conditions (third letter) for the arid climates (B) as well as for the warm temperate and snow climates (C) and (D), respectively, where T_{mon} denotes the mean monthly temperature in °C.

A description of the symbols and the criteria used to define the Köppen-Geiger climate types is provided in Table 1. The 31 possible climate types in Table 1 are divided into :

- 3 *A tropical* (Af, Am and Aw), $\{As\}$
- 4 *B arid* (BWh, BWk, Bsh and Bsk),
- 6 *C temperate* (Csa, Csb, Cfa, Cfb, Cwa, and Cwb), $\{Cfc, Csc, Cwc\}$
- 9 *D cold* (Dsd, Dfa, Dfb, Dfc, Dfd, Dwa, Dwb, Dwc and Dwd), $\{Dsa, Dsb, Dsc\}$
- 2 *E polar* (ET and EF).

In the present report only 24 zones have been retained, the ones not considered are : As (interchanged with Aw); Cfc, Csc, Cwc, Dsa, Dsb, and Dsc. They occur only in very small areas¹⁹ and are added to the closest larger one.

For better understanding of the geographical distribution of the climate zones, a description along the different continents is here presented:

Africa. Africa shows that only three (A, B and C) of the main climate types are present. Of these three the dominant climate type by land area is the arid *B* (57.2%), followed by tropical *A* (31.0%) and temperate *C* (11.8%).

Asia. Asia is defined as the region east of a north south line through the Urals Mountains down to the Arabian Sea.

Asia shows that all five climate types are present in Asia. The dominant climate type by land area is the cold *D* (43.8%), followed by arid *B* (23.9%), tropical *A* (16.3%), temperate *C* (12.3%) and polar *E* (3.8%).

Europe*. Europe is defined as the region west of a north south line through the Urals Mountains down to the Arabian Sea and includes the Arabian Penin-sula and the countries of the Middle East.

Europe shows that only four main climate types are found in Europe. The dominant climate type by land area is cold *D* (44.4%), followed by arid *B* (36.3%), temperate *C* (17.0%) and polar *E* (2.3%).

Northern America includes Canada, the USA, the countries of Central America and the Caribbean Islands.

In Northern America all five of the main climate types are present. The dominant climate type by land area is cold *D* (54.5%), followed by arid *B* (15.3%), temperate *C* (13.4%), polar *E* (11.0%) and tropical *A* (5.9%).

South America includes three main climate types A, B and C. Of these three the dominant climate type by land area is tropical *A* (60.1%), followed by temperate *C* (24.1%) and arid *B* (15.0%). The Polar *E* (0.8%) climate type occurs in four places in South America, twice in the Andes, due to the high elevation.

Australia shows that only three main climate types are found in Australia. The dominant climate type by land area is arid **B** (77.8%), followed by temperate *C* (13.9%) and tropical *A* (8.3%).

*The inclusion of the Arabian Peninsula and the Middle East will not be followed in the statistical analysis from FAO, thus the UN definitions of the continents will be maintained for what follows.

Table 2 Summary Continents & Climate Classes

Continent	A in % [Tropical]	B in % [Dry]	C in % [Temperate]	D in % [Continental]	E in % [Polar]
Africa	31,0	57,2	11,8	-	-
Asia	16,3	23,9	12,3	43,8	3,8
Europe	-	36,3	17,0	44,4	2,3
Northern America	5,9	15,3	13,4	54,5	11,0
South America	60,1	15,0	24,1	-	0,8
Australia	8,3	77,8	13,9	-	-
Planet-globally	19,0	30,2	13,4	24,6	12,8

The Climate Zones are identified per country, when more than one zone is present, the distribution is expressed in percentage of surface, which is then further used for other the parameters (crops, meat, land for agriculture, fresh water withdrawal, etc.). The basic structure of the project is given in the following order : Climate Zones (24), continents (5), countries (150).

1.3 UN-Demography Data

Humankind²⁷ shows since several decades a strong increase -hyperbolic- of its demography, which will increase with an additional 50% this century - from 6,07 to 9,06 and 'stabilize or peak' around 9-10 billion people. Is such a number sustainable for our planet?

UN demographic²⁸ data are also available per continent and over a long period of time : 1950-2300. In Fig 3 the data are drawn for the African Continent for the period from 1950 to

2300. The curves for the other continents are similar to this one. Important is that the population will enter into a plateau-like profile, still with some fluctuations; and the inflection point of the curve -first derivative equals zero- lies by 2050.

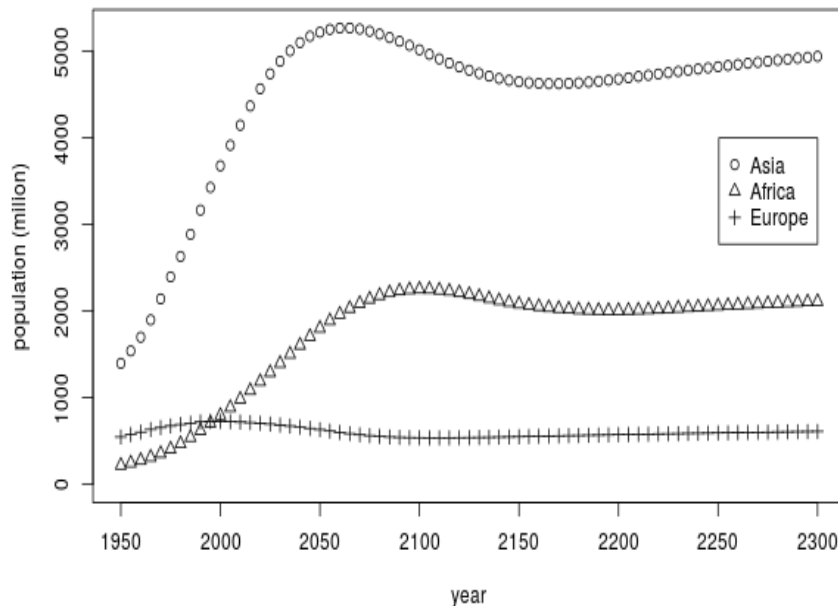
In what follows the time-frame has been limited to the year 2100, which corresponds to the major increase of the planetary population. This approach will be used for discussing scenarios of the changes to come of : the demographic numbers, the societal transitions and the biosphere, all under stress of climate change and pressure from the human activities.

In conclusion the demographic increase will come to an end say by the end of century and thereafter 'stabilize', however this under the assumption that no major disruption take place in the mean time at planetary level. However, major disruptions, at planetary scale, can be linked to dramatic climate changes, such as water availability as a consequence of the melting down of massive mountain ice, disturbing the provision of the necessary water supply for food production and health care. Other disruptions are thinkable and linked to urban social an environmental instabilities a.o.

- Populations of Continents

Fig 3. The demographic evolution of three continents

X-axis in years from 1950-2300, the Y-axis the population (million)



In Table 3a the data for the continents are shown, but limited to 2100. These data per continent are quite relevant, and show impressive differences in evolution. The choice of continents together with climate zones confirms a substantial advantage for calculating

realistic scenarios.

Table 3a Demographic extension for different periods and continents

Continents	1950 million	2000 million	2010* million	2015 million	2050 million	2100 million
Africa	221.2	795.7	984.2	1,084.5	1,803.3	2,254.3
Asia	1,398.5	3,679.7	4,148.9	4,370.5	5,222.1	5,019.2
Europe	547.4	728.0	719.7	713.4	631.9	538.4
Lat.-Am & Carib.	167.1	520.2	594.4	628.3	767.7	732.5
Northern Am.	171.6	315.9	348.1	364.0	447.9	473.6
Oceania	12.0	31.0	34.8	36.6	45.8	46.1
World	2,517.8	6,070.5	6,830.1	7,197.3	8,918.7	9,064.1

- The amount of world population in 2010 is slightly different compared with data from other sources. The observed differences are within acceptable statistical limits.

In Table 3b the data are presented in terms of ratios over the given time periods. The demographic evolution from 1950 to 2100 are simply overwhelming : in some five generations the world population as grown from 2,5 to 9,1 billion people or by a factor ~3.5; this century by a factor ~1,5.

Table 3b Ratios of population growth for different periods and continents

	Ratio 1950-2100	Ratio 2000-2100	Ratio 2010-2100
Africa	10.19	2.83	2.29
Asia	3.59	1.36	1.21
Europe	0.98	0.74	0.75
LatAm & Carib.	4.38	1.41	1.23
Northern Am	2.76	1.50	1.36
Oceania	3.60	1.49	1.32
World	3.60	1.49	1.33

The **African continent** shows an dramatic increase of its population for the period of this century with a factor of 2,83, whereas the population of the planet will increase by another ~50% (1,49), resulting in an additional 3 billion people, which is almost half the existing population on earth.

The population of the **European continent** will decrease by 2100 and quite significantly: ~25% compared to the year 2000. In fact the population is already decreasing today, unless immigration is compensating the ongoing decline.

The remaining continents **Asia**, **Latin America & Caribbean**, **Northern America** and **Oceania** have a growth factor of about 1,36 to 1,50, which corresponds with the average increase of the world population.

As an intermediate conclusion, the demographic increase is the most sensitive in the African Continent in terms of numbers with a factor 2,83 over the 21st century. How the world community will cope with such an increase of new born individuals remains a dramatic question. Namely, to provide education at all levels, to provide health-care and hospitals, to build shelters and decent housing, to build and extend infrastructure for communication, etc. This is far from evident.

For the entire planet the challenge of agriculture output or food production for an additional ~3 billion people is an Herculean task, the more that already today almost one billion humans are suffering malnutrition and hunger.

- *Population in Climate Classes*

The population distribution over the different climate classes is an interesting exercise which is illustrated below.

Table 4 Population distribution over the major climates

Climate Class	Description Climate	Population in billion
A	Tropical/megathermal	1,95
B	Dry -arid & semi-arid	1,96
C	Temperate/mesothermal	1,74
D	Continental/microthermal	1,20
E	Polar & alpine	0,058
Sum	Planet	6,908

The A,B,C Climate Classes have about the same population amounts; Climate Class D has a much smaller number of 1,2 billion people. Whereas the Climate Class E (polar and alpine climates) is almost negligible with 0,058 billion people. Surprisingly the Tropical (A) and the Dry (B) Climate Zones, including substantial dessert surfaces, not particular attractive for living and food production, have about 4 billion people, whereas the Temperate (C) and the Continental (D) Climate Zones ~3 billion people.

Chapter 2. Agricultural Production. Data Compilation

The impressive amount of data available from the FAO^{29, 30} statistical department facilitated substantially the analysis of the present planetary situation of food production.

The compiled data cover major food products : crops -rice, wheat and maize- and, meat -beef, pigs, sheep/goat and poultry. These items are completed with the physical environment for production : arable land and water-withdrawal. Although there are much more food products consumed by humans, the limited choice of the major dietary products should provide a fair basis of the food challenge of a much larger world population of some >10 billion people.

Besides the choice of Köppen-Geiger Climate Classification System, much attention is given to the continents, Africa, Asia, Europe inclusive the Russian Federation, Ukraine and Belarus, Northern America inclusive Middle America and South America inclusive Australia and New Zealand. Aligning the continents with the Climate Zones and their demography throws very interesting observations as will appear from the analyses.

The amounts of crops and meat production of the different continents are related to the population, which again leads to interesting the conclusions.

2.1 Crops & Meat Production Data

The five continents have generally well defined geographical boundaries and are composed by countries with legal UN-status. The continents have quite different behaviors in terms of population growth, food production and climate properties.

2.1.1 Data per Continent & Country

The data for the Northern America being North and Middle America (NAM) for crops and meat for 2010 are listed in the Appendix volume.

- Afri. Africa has been kept unchanged;
- Asia. Asia minus those added to EUR.
- EUR. The Russian Federation, Ukraine, Belarus and Georgia have been added to EUR (instead of Asia);
- NAM. Northern America includes North and Middle America (NAM);
- SAM. South America includes Oceania -but limited to Australia and New Zealand (SAM).

The data compilation has been performed for all the continents, very small surfaces within a Climate Zone -generally $\sim < 3\%$ - of a country are added to larger ones of that country. Island

groups are not taken into account, for they do not play a significant role at the scale of planetary agriculture output. The CZs are identified per country, when more than one zone is present, the distribution is expressed in percentage of the surface, which is then further used for the other parameters (crops, meat, land, fresh water availability, etc.).

2.1.2 Summary of the data of Crops & Meat per Climate Classes & Zones (CZ)

In Table 5 are given the data for the Climate Zones and Climate Classes of the entire planet for : population, three crops and four meat. The five Climate Classes (A,B,C, D,E) and 24 Climate Zones are represented.

Table 5 Climate Zones, their population and agriculture outputs.

CZ	Climate Zone	Population # 2011	Crops			Meat			
			Rice 10 ⁶ tons 2010	Wheat 10 ⁶ tons 2010	Maize 10 ³ tons 2010	Beef 10 ³ tons 2010	Pigs 10 ³ tons 2010	Sheep+goat 10 ³ tons 2010	Poultry 10 ³ tons 2010
Af	equatorial climate	440,168	91,171	931	32,198	2,839	3,707	186	6,399
Am	monsoon climate	299,429	53,041	5,492	23,591	3,058	1,918	230	4,469
Aw	tropical savanna climate	1,207,433	156,904	34,631	75,606	8,768	4,831	1,360	10,603
Sum A		1,947,030	301,116	41,054	131,395	14,665	10,456	1,776	21,471
Bsh	warm desert climate	735,896	66,652	53,976	68,768	5,107	9,588	1,619	6,713
Bsk	cold desert climate	158,209	3,959	27,874	14,841	2,305	1,901	652	3,018
Bwh	warm semi-arid climate	646,818	26,574	54,971	23,292	5,369	489	2,247	5,169
Bwk	cold semi-arid climate	420,316	49,668	44,367	51,256	3,250	12,759	1,405	5,411
Sum B		1,961,239	146,853	181,188	158,157	16,031	24,737	5,923	20,311
Csa	warm mediterranean climate	193,584	4,304	31,599	69,312	3,646	3,530	517	6,300
Csb	temperate mediterranean climate	47,930	1,209	5,519	4,560	724	1,044	106	1,010
Cwa	humid subtropical climate	684,878	100,153	38,998	43,698	3,096	7,127	855	4,205
Cwb	humid sub trop clim/subtrop oceanic highland clim	194,647	21,269	11,978	14,791	942	2,333	305	1,418
Cfa	warm oceanic climate/humid subtropical climate	334,564	35,306	30,350	45,008	4,305	8,463	686	5,562
Cfb	temperate oceanic climate	230,292	859	67,427	21,477	5,448	9,696	1,043	6,288
Cfc	cool oceanic climate	59,368	2,002	11,101	57,168	2,208	1,928	17	3,638
Sum C		1,745,263	165,102	196,972	256,014	20,369	34,121	3,529	28,421
Dsa	warm continental clim/mediterranean continental clim	39,002	1,014	8,158	1,551	361	14	163	442
Dsc	cool continental climate	23,228	772	5,131	22,601	894	791	7	1,421
Dwb	temperate continental climate/humid continental clim	343,871	48,396	28,421	43,312	1,631	12,439	984	4,195
Dwc	cool continental climate/subarctic climate	616	0	76	0	11	0	28	0
Dwd	cold continental climate/subarctic climate	17,032	127	4,981	370	207	280	22	313
Dfa	warm continental climate/humid continental climate	101,166	5,802	9,929	42,474	1,846	2,085	58	3,112
Dfb	temperate continental clim/humid continental clim	514,096	29,576	98,117	104,938	6,162	17,505	678	11,191
Dfc	cool continental climate/subarctic climate	177,516	2,645	52,253	67,458	4,107	4,714	181	6,053
Sum D		1,216,527	88,332	Err:522	282,704	15,219	37,828	2,121	26,727
EF	tundra climate	9,516	331	1,802	9,484	363	308	6	591
ET	ice cap climate	48,493	199	16,061	5,304	938	1,492	44	1,003
Sum E		58,009	530	17,863	14,788	1,301	1,800	50	1,594
Sum 24		6,928,068	701,933	Err:522	843,058	67,585	108,942	13,399	98,524

- Synthesis. Crops & Meat output per Continent (6a) & Climate Class (6b)

For clarity a synthesis of the manifold of data -about 5,000- for crops and meat have been put together per continent Table 6a, and Climate Class in Table 6b. Large differences do exist among the continents, depending on their geographic situation e.g. rice production and cultural customs e.g. pigs output.

Table 6a Synthesis Crops & Meat Output per Continent

Continents	Population mio 2010	Crops			Meat			
		Rice 10 ³ tons 2010	Wheat 10 ³ tons 2010	Maize 10 ³ tons 2010	Beef 10 ³ tons 2010	Pigs 10 ³ tons 2010	Sheep+goat 10 ³ tons 2010	Poultry 10 ³ tons 2010
Africa	1,032,186	23,172	22,375	66,258	6,668	1,234	2,876	4,827
Asia	4,190,220	637,668	290,396	254,714	16,609	61,961	7,647	34,617
Europe	742,825	4,304	194,406	78,311	10,993	26,817	1,296	16,203
NAM	538,924	13,671	87,242	352,256	15,650	13,662	215	24,645
SAM	423,913	23,118	49,724	91,519	17,665	5,268	1,365	18,232
Sum-Conti	6,928,068	701,933	644,143	843,058	67,585	108,942	13,399	98,524

Table 6b Synthesis Crops & Meat Output per Climate Class

Climate Class	Population mio 2010	Crops			Meat			
		Rice 10 ³ tons 2010	Wheat 10 ³ tons 2010	Maize 10 ³ tons 2010	Beef 10 ³ tons 2010	Pigs 10 ³ tons 2010	Sheep+goat 10 ³ tons 2010	Poultry 10 ³ tons 2010
Sum A	1,947,030	301,116	41,054	131,395	14,665	10,456	1,776	21,471
Sum B	1,961,239	146,853	181,188	158,157	16,031	24,737	5,923	20,311
Sum C	1,745,263	165,102	196,972	256,014	20,369	34,121	3,529	28,421
Sum D	1,216,527	88,332	207,066	282,704	15,219	37,828	2,121	26,727
Sum E	58,009	530	17,863	14,788	1,301	1,800	50	1,594
Sum-CZ	6,928,068	701,933	644,143	843,058	67,585	108,942	13,399	98,524

2.1.3 Per capita output Crops & Meat

The same data of the above tables but related to the population number (per capita) are compiled in the Tables 7a & 7b. A much better picture emerges from this calculation and stresses again the big differences that exist among the continents and their food provision today.

The quantities of crops/ca and meat/ca production differ substantially among the continents. The *African continent* scores lower values over all production units, and taking into account

that the population, up to the end of this century, will increase by a factor 2,83 (see Table 3a), a serious -if not dramatic- challenge has to be faced.

Table 7a Synthesis. Crops & Meat per Continent per CAPITA

Continents	Population mio 2010	Crops			Meat			
		Rice kg/ca/y 2010	Wheat kg/ca/y 2010	Maize kg/ca/y 2010	Beef kg/ca/y 2010	Pigs kg/ca/y 2010	Sheep+goat kg/ca/y 2010	Poultry kg/ca/y 2010
Africa	1,032,186	22.4	21.7	64.2	6.45	1.20	2.79	4.68
Asia	4,190,220	152.2	69.3	60.8	3.96	14.79	1.82	8.27
Europe	742,825	5.8	261.7	105.4	14.80	36.10	1.74	21.81
NAM	538,924	25.4	161.9	653.6	29.04	25.35	0.40	45.73
SAM	423,913	54.5	117.3	215.8	41.66	12.54	3.22	43.00
Sum-Conti	6,928,068	101.3	93.0	121.7	9.75	15.72	1.93	14.22

The other continents show a better overall picture, although some differences among the crops, e.g. rice-wheat, do exist. Europe and Northern America have the highest production/ca amounts.

In Table 7b the same data are correlated to Climate Classes; A (Tropical) and B (Dry) with highest population density, show lower output quantities/ca -except for rice- compared to C (Temperate) and D (Continental), but both have lower population and E (Polar) is overall negligible.

Table 7b Synthesis. Crops & Meat per Climate Class per CAPITA

Climate Class	Population mio 2010	Crops			Meat			
		Rice kg/ca/y 2010	Wheat kg/ca/y 2010	Maize kg/ca/y 2010	Beef kg/ca/y 2010	Pigs kg/ca/y 2010	Sheep+goat kg/ca/y 2010	Poultry kg/ca/y 2010
Sum A	1,947,030	154.7	21.1	67.5	7.53	5.37	0.91	11.03
Sum B	1,961,239	74.9	92.4	80.6	8.17	12.61	3.02	10.36
Sum C	1,745,263	94.6	112.9	146.7	11.67	19.55	2.02	16.29
Sum D	1,216,527	72.6	170.3	232.5	12.52	31.11	1.74	21.98
Sum E	58,009	9.1	307.9	245.9	22.43	31.03	.86	27.48
Sum-CZ	6,928,068	101.3	93.0	121.7	9.75	15.72	1.93	14.22

2.2 Land Area for Agriculture and Water-withdrawal

In a similar way as with crops and meat, the analysis is extended to available land for agriculture and fresh water withdrawal, both for the food production. The methodological

approach remains identical as with Climate Classes and Zones, the continents and population.

Land for agriculture : food and animal husbandry including *pasture*, are increasingly a source of concern. Uncontrolled expansion for infrastructure (roads, cities and suburbs, etc.), increasing migration of people from farms towards cities resulting in a population density of about 70% in cities by the end of the century, extreme weather conditions due to intense rainfalls and storms, increased desertification of entire regions, all reduce available land for agriculture reserves.

Increasing the overall efficiency of crops and meat output, reducing the loss of nutrients in the logistic chain from the harvest to the dishes of the people, are insufficient for answering the rising need for food. The available land for agriculture is a question to be addressed very seriously, and is, in the long run, a matter of global governance.

Forests. If additional land would be made available through the elimination of *forests*, as is already practiced for some decades in some continents, the equilibrium of atmosphere-biosphere would be modified and probably in irreversible ways, resulting in additional impact on global warming. Indeed, forests play a significant role in the *thermodynamic* and *hydrodynamic* conditions of the planet : dynamic interaction of the atmosphere with the forests surface; rainfall, humidity and average temperature. Forests play an essential role in maintaining the *terrestrial bio-diversity* as well.

Their role is not only related to agriculture and timber production, but also to the 'physical' conditions of the planet and the process of the climate stability.

Fresh water situation. Unfortunately in several regions of the terrestrial planet the surface and freatic water tables are dangerously polluted as well as their quantities are decreasing rapidly. Additionally, in the high mountain regions, the fresh water availability is threatened in summer periods, which will become disastrous for food production due to lack of fresh water in the warmest and most productive season of the year. The populations living along very large river basins, especially in Asia, risk to be severally hit by this phenomenon. Some scientists indicate that in the long run, the freshwater availability is by far more critical for the human species than any other concern on material resources.

Animal husbandry. The industrial practice of producing animals for food in entire artificial environments, as is already the case for pigs and poultry, tends to be extended to other animal species and will contribute to some relieve of food scarcity. The extension of these practices is on the way to be applied to beef production and derivatives. In principle it could liberate the use of land for meadows and pastoralist, creating potentially land for crops production.

Biofuel. The production of biofuel using crops for human consumption, not only diminishes the available food for humans, but the land for agriculture and water-withdrawal as well. Obviously, these *unsustainable* practices have to be stopped straightaway.

2.2.1 Land for agriculture & Water-withdrawal

The compilation of the data of Land for agriculture and Water-withdrawal of continents and countries is based on the same FAO report *Statistics 2013*. In Table 8 are, as an example, listed data for the terrestrial planet for the Climate Classes A to E and their Climate Zones. All the continents have been compiled separately, the synthesis of these results are shown in the different tables below. In the Annex Volume (in progress) the data of Land for agriculture and Water-withdrawal for the other continents are listed.

Table 8 Summary per Climate Zone for the entire Terrestrial Planet

Climate Zones	Population # Thous.	Agriculture area					Water-withdrawal	
		Total Land	Total Agri	Arable Area	Crops	Meadows/ Pastures	Total	Agricul.
		Tkm ² 2009	Tkm ² 2009	Tkm ² 2009	Tkm ² 2009	Tkm ² 2009	mio m ³ /y ~2000	mio m ³ /y ~2000
Af	440,168	5,509	1,524	437	304	782	225,787	177,646
Am	299,429	4,687	1,424	453	93	878	127,753	103,458
Aw	1,207,433	16,063	6,354	2,108	334	3,909	468,052	397,480
A	1,947,030	26,259	9,298	2,998	731	5,569	821,592	678,583
Bwh	646,818	20,920	8,655	1,288	95	7,270	425,518	372,811
Bwk	420,316	8,077	4,548	790	81	3,674	239,669	180,746
Bsh	735,896	11,184	5,834	1,407	117	4,309	368,250	321,946
Bsk	158,209	5,390	3,125	502	50	2,571	151,326	126,620
B	1,961,239	45,571	22,162	3,988	343	17,825	1,184,764	1,002,123
Csa	193,584	3,167	1,396	570	64	763	184,906	103,492
Csb	47,930	1,206	462	100	20	342	23,051	15,019
Cwa	684,878	6,462	2,942	929	95	1,918	353,975	129,563
Cwb	194,647	2,263	1,112	296	28	787	87,983	72,601
Cfa	334,564	5,484	2,706	605	68	2,033	172,916	104,594
Cfb	230,292	2,467	1,278	423	30	825	99,129	22,389
Cfc	59,368	1,788	756	295	6	455	88,273	36,134
C	1,745,263	22,835	10,651	3,217	311	7,123	1,010,233	483,792
Dsa	39,002	545	312	95	9	208	37,019	32,482
Dsc	23,228	1,016	312	132	5	176	35,350	13,689
Dwb	343,871	4,649	2,633	569	71	1,993	21,578	15,927
Dwc	616	341	255	2	0	253	112	50
Dwd	17,032	1,966	259	146	2	110	7,944	1,581
Dfa	101,166	1,751	883	312	8	563	100,608	49,119
Dfb	514,096	11,227	4,030	1,715	85	2,233	308,586	131,841
Dfc	164,742	14,502	2,209	1,168	47	994	149,302	45,034
Dfd	12,774	1,474	194	110	2	83	5,958	1,186
D	1,216,527	37,470	11,089	4,249	228	6,612	666,456	290,908
ET	48,493	5,562	548	325	27	197	30,645	4,699
EF	9,516	602	132	49	1	82	14,419	5,798
E	58,009	6,163	680	373	28	279	45,064	10,497
SUM	6,928,068	138,299	53,880	14,825	1,642	37,408	3,728,108	2,465,903
A,B,C,D,E								

2.2.2 Synthesis of the data of Land for Agriculture & Water-withdrawal

- Land & Water-withdrawal per Continent & per Climate Classes

Land use. The ratio of the *total amount* of land to the amount available land for *agriculture* is for the continents (Table 9a) : A ~35%; B ~48%; C ~47%; and D ~30%. For E it is only ~16%, however given the the specific climate circumstances, it will not be taken into account.

The ratio (in percentage) of land for *crops* compared land for *meadows & pastures* is for the Climate Classes (Table 9b) : A ~13,1%; B ~1,9%; C ~4,4%; D ~3,5% and E ~10,0%; globally the ratio is ~4,4%. Surprisingly the surface used for crops production is rather modest compared to meadows & pastures. At a global level there seems to be considerable reserves for extending crops production surfaces, although it must be recognized that not all land used for meadows & pastures can be transformed to land for crops production, due to geographical situations, and for those parts of land which could be adapted to crops production additional investments will be required to obtain acceptable efficiency.

With increasing population and the rising average living standards, the demand for meat will enhance the demand for vegetation for fodder, as well as meadows/ pastures areas and water-withdrawal. However, the expected required surface for animal husbandry could be reduced to a strict minimum, as is already the case for pigs and poultry, at least in industrialized countries. This technological evolution may not be applicable or appreciated, for now, in every country, however the provision of enough food for everybody could require such 'quantum jumps'. The production of fodder has to be continued and has to follow the demand for meat. The important variety in surface size and soil quality suggests that quite more space could be made available for growing crops. However, this conclusion could be rather optimistic, for the quality of the soil has as well as geographical conditions have to be taken into account. For example: e.g. Alpine and high mountain areas will remain usable as meadows and pastures, but difficult to allow large scale crops production.

Table 9a Synthesis Population, Land & Water-withdrawal per Continent

Continent	Population Thous. #	Total Land Tkm ² 2009	Total Agri Tkm ² 2009	Agriculture Area			Water Withdrawal	
				Arable Area Tkm ² 2009	Crops Tkm ² 2009	Meadows Pastures Tkm ² 2009	Total mio m ³ /y ~2000	Agricul. mio m ³ /y ~2000
Africa	1,032,186	29,399	11,432	2,164	283	8,985	179,467	148,494
Asia	4,190,220	40,078	21,616	5,853	900	14,862	2,367,239	1,817,702
EUR	742,825	22,119	4,743	2,778	157	1,807	362,648	101,628
NAM	538,924	21,209	6,000	2,427	161	3,412	623,237	272,206
SAM	423,913	25,495	10,085	1,602	140	8,342	195,517	125,872
SUM	6,928,068	138,299	53,875	14,825	1,642	37,408	3,728,108	2,465,903

Table 9b Synthesis Population, Land & Water-withdrawal per Climate Class

Climate Zones	Population # Thous.	Total Land Tkm ² 2009	Total Agric. Tkm ² 2009	Agriculture area			Water Withdrawal	
				Arable Area Tkm ² 2009	Crops Tkm ² 2009	Meadows Pastures Tkm ² 2009	Total mio m ³ /y ~2000	Agricul. mio m ³ /y ~2000
A	1,947,030	26,259	9,298	2,998	731	5,569	821,592	678,583
B	1,961,239	45,571	22,157	3,988	343	17,825	1,184,764	1,002,123
C	1,745,263	22,835	10,651	3,217	311	7,123	1,010,233	483,792
D	1,216,527	37,470	11,089	4,249	228	6,612	666,456	290,908
E	58,009	6,163	680	373	28	279	45,064	10,497
SUM	6,928,068	138,299	53,875	14,825	1,642	37,408	3,728,108	2,465,903

- **Water-withdrawal.** The total water withdrawal (mio m³/y) for agriculture compared the total amount available is quite high and varies substantially depending on the Climate Classes : for A and B it amounts to from ~80% to ~84%; for C and D from ~48% to ~43%; and for the E ~23%.

For comparison the individual water use is estimated to be 150 to 400 liters water per day per person (52,5 to 140m³/y/ca) in industrialized societies. To a certain extend the use per capita for personal and domestic use is lower than for agriculture output, here expressed per year (Tables 10a, 10b).

The world wide increase of the demography and shift of water availability in CZ due to global warming and local extreme weather conditions, the global water situation, becomes a critical issue for the well-being of several human communities.

Table 10a Synthesis : Land & Water-withdrawal per Continent & per Capita

Continent	Population Thous. #	Total Land 10 ⁻³ km ² /ca 2009	Total Agri 10 ⁻³ km ² /ca 2009	Agriculture Area			Water-withdrawal	
				Arable Area 10 ⁻³ km ² /ca 2009	Crops 10 ⁻³ km ² /ca 2009	Meadows Pastures 10 ⁻³ km ² /ca 2009	Total m ³ /y/ca ~2000	Agricul. m ³ /y/ca ~2000
Africa	1,032,186	28.50	11.08	2.10	0.27	8.71	173.90	143.89
Asia	4,190,220	9.56	5.16	1.40	0.21	3.55	564.94	433.80
EUR	742,825	29.78	6.38	3.74	0.21	2.43	488.20	136.81
NAM	538,924	39.35	11.13	4.50	0.30	6.33	1,156.45	505.09
SAM	423,913	60.14	23.79	3.78	0.33	19.68	461.28	296.93
SUM	6,928,068	19.96	7.78	2.14	0.24	5.40	538.12	355.93

Table 10b Synthesis : Land & Water-withdrawal per Cl. Class & per Capita

Climate Zones	Population # Thous.			Agriculture area			Water Withdrawal	
		Total Land 10 ⁻³ km ² /ca 2009	Total Agric. 10 ⁻³ km ² /ca 2009	Arable Area 10 ⁻³ km ² /ca 2009	Crops 10 ⁻³ km ² /ca 2009	Meadows Pastures 10 ⁻³ km ² /ca 2009	Total m ³ /y/ca ~2000	Agricul. m ³ /y/ca ~2000
A	1,947,030	13.49	4.78	1.54	0.38	2.86	422.00	348.50
B	1,961,239	23.44	11.30	2.03	0.18	9.09	604.09	510.92
C	1,745,263	13.09	6.10	1.84	0.18	4.08	576.50	275.92
D	1,216,527	42.65	9.12	3.49	0.19	5.44	551.36	241.06
E	58,009	111.42	11.72	6.43	0.48	4.81	776.91	180.97
SUM-Aver.	6,928,068	19.96	7.78	2.14	0.24	5.40	538.12	355.93

The numbers are approximate for, neither corrections have been made for the impact of global warming on crops production, nor on meadows (and soil) behavior, nor for urbanization and infrastructure. Interesting is that the ratio shows the same magnitude except for Latin America (Oceania not included here, see Table 3a).

The ratio of *land for meadows* to *land for crops* and extrapolated to 2100 -in the Table 11a- provides an approximate view of the evolution of the use of land for agriculture. Evidently the today's ratio (X) for Africa looks quite attractive for expanding to crops production, however the apparent advantage disappears with strong population growth by 2100.

Table 11a

Continent	Land ratio X = meadows/crops 2010	Y= Population growth factor 2010- 2100	Land ratio Z=X/Y 2100
Africa	32.2	2.29	14.1
Asia	16.9	1.21	14.0
Europe	11.6	0.75	15.4
NAM	21.1	1.23	17.2
SAM	59.6	1.36	43.1

In Table 11b the ratio *Water-withdrawal* for agriculture compared to domestic use shows little reserves for the future. Taking into account the population increase, in particular for Africa there will be considerable shortage, for agriculture (expressed through >1) as well as for other use. The future situation for Asia and SAM do not look attractive either.

Table 11b

Continent	Water-withdr. ratio X = agriculture/total ~2010	Y= Population growth factor 2010-2100	Water-withdrawal Agriculture. Ratio 2100 Z=X*Y
Africa	0.827	2.29	>1
Asia	0.768	1.21	0.9
Europe	0.280	0.75	0.2
NAM	0.437	1.23	0.5
SAM	0.644	1.36	0.9

The above estimations should be explored in greater detail. Indeed, for continents specific corrections for inhabitable surfaces have to be included in the analysis such as : deserts (increasing), high mountain chains, tropical forests (decreasing), etc. However this is beyond the topic of this research.

In Table 11c another way of looking at the climate classes up to 2100 on the ratio of land for meadows to crops under the effects of demographic increase. Evidently that ration is decreasing the fastest where population is the highest, meaning that the potential for transforming meadows to crops land is decreasing as well. This is particularly the case for the Climate Class B, the largest one on earth.

Table 11c

Class	Population 2010	Population 2100	Ratio Population Y 2100/2010	Land Ratio* Meadows/crops X	Ratio Z=X/Y 2100
A	1,947,030	2,896,542	1.488	7.618	5.12
B	1,961,239	2,852,231	1.454	50.520	35.74
C	1,745,263	2,088,549	1.197	22.720	19.13
D	1,216,527	1,305,536	1.073	28.630	27.03
E	58,009	55,395	0.955	10.020	10.43
Sum/ Average	6,928,068	9,198,253	1.328	-	-

* Values taken from Table 9b

In an intermediate conclusion, the data in the tables 9 to 11 show that the availability of land and fresh water for agriculture decrease with substantially with demographic evolution. From the two resources, fresh water is the most critical, it concerns all biological life including human life.

Chapter 3. Software for Network Description & Results

Two *open source* tools have been used so far :

- the first one, is a graphical tool known as **Gephi**³¹, which in the first place provides **graphical output**, as well as **statistical data** about the network. The network diagrams of Fig. 4a & 4b, 5, 6 have been obtained with it.
- the second one, the use of the program language, **R**^{32,33,34} and provides different graphical representation of the same networks, Fig 7, 8, 9 and 10.

3.1 Applying Gephi software. Statistical data

3.1.1 Crops & Meat Production

- Graphical Output

The data shown in the tables of the Annex provide the data for the different continents: Africa, Asia, Europe, Northern America and South America for population, crops and meat for the five Climate Classes and the Climate Zones as defined in the Köppen-Geiger classification system. In Table 6a & 6b (page 25) are the data listed for crops & meat output per continent resp. per climate class, and in Table 7a & 7b (page 26) are the same data per capita. The graphical results of the network calculations, shown in Fig. 4a & 4b, are obtained with the *Gephi* software.

- *Crops*. The crops chosen for this research are limited to rice, wheat and maize, all for the year 2010. Other crops can be added without any restriction and are available in the FAO databases.

Since the research is limited to terrestrial resources, ocean, sea and river fisheries are not included, although they have some importance, at least for specific populations living close to these resources : in 2012 the world production of fish was 158 millions tonnes, of which 66,6 million tonnes by aquaculture³⁵.

As a parenthesis, a comment on crops for the production of **bio-fuel**^{37,38} using agriculture output (food) for the manufacturing this energy source. A major challenge arises through the use of crops for the production of fuel as energy source for industrial and individual use. These vegetable sources -wheat, maize, sugar cane, a.o.- are in direct competition for food for human use, and additionally, deviate soil and fresh water use indispensable for food production. The elimination of forests and their services have an unsustainable impact as well : decreased carbon dioxide fixation, loss of bio-diversity, etc. According to *Reading Soil Science*³⁹ in 2010 the ethanol production will consume 15% of global grain production and 30% of global sugar cane production; bio-fuel production will consume 10% of global vegetable oil production. The wrong use of these resources needed for food production and other services are definitely unsustainable and disastrous, in the long

term, for the human species.

- *Meat*. In order to have a correct understanding of food output for human consumption, today and increasingly in the future, the part of resources of land and fresh water for the meat production has to be included into total agriculture output. For the meat production, four types have been selected : beef, pigs, sheep & goat and poultry, all for 2010 from the same FAO report.

It is very well known that meat production has a very low energy efficiency ratio³⁸ (input/output), e.g. for beef 6:1, for pigs 3,5:1 and for poultry 2:1. In Fig 4a & 4b are the network data shown for the European continent (EUR) and the entire Terrestrial Planet, being the sum of the five continents. The leading parameter is Climate Zones which is visible in both the diagram below, letters in circles.

Both graphs are similar in structure, as are the ones for the remaining continents, not shown here but include in the Annex Volume. The networks themselves do not look very sophisticated, however the impact of global warming on the major climate zones and their agricultural output, are likely very important, if not determinant, for certain regions, which will be addressed later.

Fig 4a Network for meat for the European Continent (EUR)
with 493 nodes and 679 edges (links).

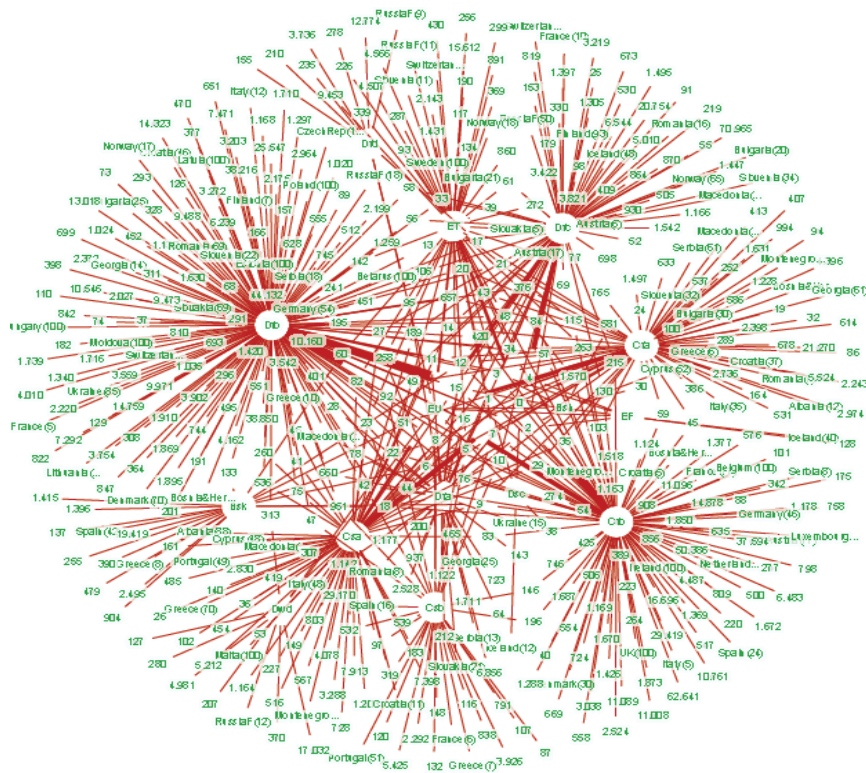
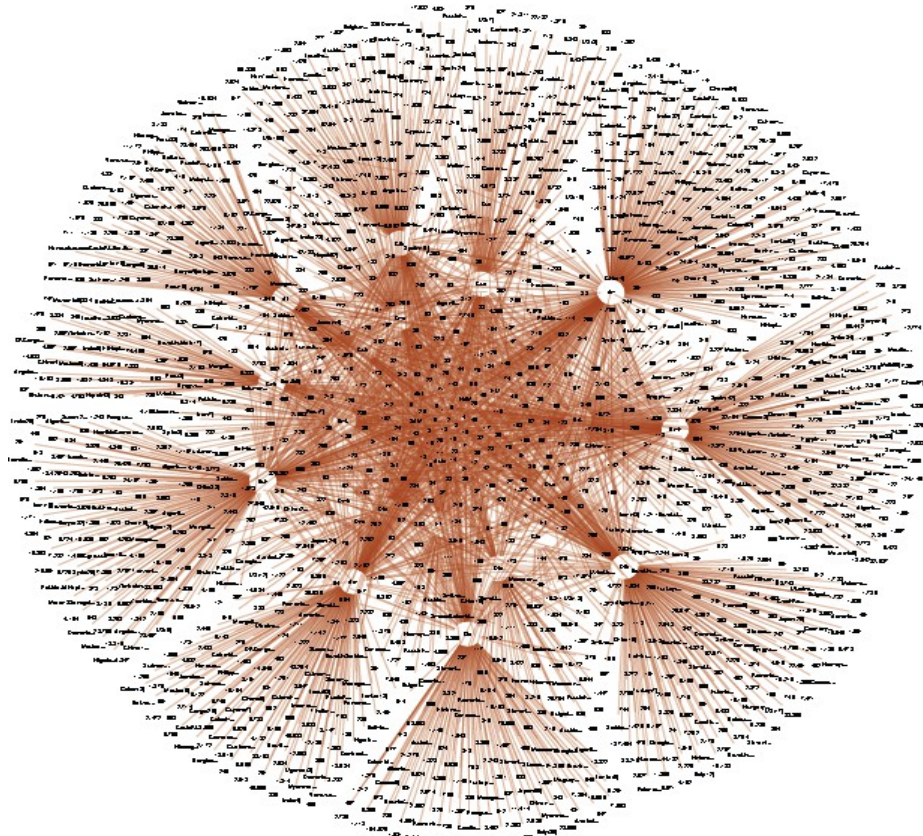


Fig 4b Network for meat of the Terrestrial Planet
with 1690 nodes and 2874 edges (links)



- Statistical Analysis of Graphics

The listed statistical properties are taken from the **Gephi** software. They are based on mathematical analysis and used in the wide variety of networks. The description of these values obtained in the present analysis, are important for positioning the type of network of the research topic.

Weighted networks. Edges can have strength, weight or value, and is represented by a positive number.

Degree. The degree of a node in a graph is the number of links connected to it. The mean degree of node in an *undirected* network is given by the relation $c=2m/n$, where c is mean degree, m the number of edges and n number of nodes.

Graph density. The graph density ρ expresses the fraction of these links actually present and lies $0 \leq \rho \leq 1$, where $\rho = c/(n-1)$.

Path length. A path is a route across the network that runs from node to node along the link of the network. The length of a path in a network is the number of links traversed along the path.

Diameter. The diameter of a graph is the length of the longest path between any pair of nodes in the network, for which the a path actually exists.

Connected components. A network is connected if there is a path from every node in a network to every other. A connected network necessarily has only one component. A singleton node that is connected to no others has one component of size one, and every node belongs to exactly one component.

Centrality & Eigenvector centrality. The centrality in a network is the degree of edges connected to a node. The importance of a node in a network is increased by having connections to other nodes that are themselves important. Eigenvector centrality gives each node a score proportional to the sum of the scores of its neighbors.

Page Rank. It is the Trade name given by Google, and based on Katz centrality approach, which is used as a central part in their web ranking technology. The aim is to generate lists of useful web pages from a pre-assembled index of pages in response to text queries. The mathematical approach contains a parameter $\alpha = 0,85$ set by Google.

Clustering coefficient. The *clustering coefficient* is defined as the fraction of path length two in the network that are closed $c = (\# \text{ of closed paths of length two}) / (\# \text{ of paths of length two})$. The value of c lies in the range of from zero to one.

Modularity. Is a measure of the extend to which like is connected to like in a network. It is strictly less than 1, takes positive values of there are more edges between nodes of the same type than estimated or expected, and negative ones if there are less.

The Tables 12a and 12b summarize the characteristics of the networks as well as some statistical data for the different continents and the entire Terrestrial Planet. They have been defined as *undirected* networks and the graphical presentation has been based on the *Fruchterman-Reingold* and *Force Atlas 2* algorithms.

The continents have been used for the data compilation, the CZs are the leading parameters in the graphical output. For further mathematical interpretation and understanding, the book from M.E.J. Newman *Networks. An Introduction*¹⁷, will be quite helpful.

Table 12a Network Characteristics

Network Graphics & Characteristics	African Continent	Asian Continent	European Contin.	N+M Am. Continent	Lat. Am. + Ocean. Cont.	Terrestrial Planet
Nodes	460	650	493	287	375	1,690
Edges/Links	689	955	679	369	571	2,874
Ratio = Edges/Node	1.50	1.46	1.38	1.29	1.52	1.70

The number of nodes and links varies among the continents, probably related to the population density. The ratio Edges/Nodes is the highest for the entire planet (1.70) meaning that the number of links is more intensive as compared to each continent, and the lowest value for Northern Amer. (1.29) related to a low population density.

Table 12b For meat production. Statistical properties

Statistical Properties	African Continent	Asian Continent	European Continent	N.+M. Am. Continent	Lat. Am. + Oceanic Cont.	Terrestrial Planet
Network Overview						
Average Degree	2.996	2.938	2.755	2.571	3.061	3.401
Aver. weighted Degree	5.035	3.920	4.093	3.707	3.515	5.549
Graph Density	0.007	0.005	0.006	0.009	0.008	0.002
Modularity	0.360	0.469	0.433	0.510	0.541	0.371
Page Rank	0.001	0.001	0.001	0.001	0.001	0.001
Node Overview						
Eigenvector Centrality	9.75E-05	2.47E-04	3.94E-04	3.214	3.72E-04	2.17E-04
Edge Overview						
Diameter	4	4	4	4	6	6
Average path length	3.391	3.663	3.460	3.551	3.575	3.667

Some comments to the above table :

Average degree. Corresponds to $C=2*\text{edges}/\text{nodes}$ and equals the value calculated in Table above.

Average weighed Degree.

Graph Density. $0 \leq \rho \leq 1$, where $\rho = c/(n-1)$. The value is the lowest for the planet, for the continents they are rather similar.

Modularity. Measures the extend to which like is connected to like, with positive value and always < 1 , there are more edges between nodes of the same type than estimated or expected. The highest value is for Southern America

Page Rank. It is the Trade name given by Google, and based on Katz centrality approach, which is used as a central part in their web ranking technology. The aim is to generate lists of useful web pages from a pre-assembled index of pages in response to text queries. The mathematical approach contains a parameter $\alpha = 0.85$ set by Google.

Eigenvector centrality. It gives each node a score proportional to the sum of the scores of its neighbors.

Diameter. The diameter of a graph is the length of the longest path between any pair of nodes in the network, and is here 6 for Southern America and the entire planet, and 4 for the other continents.

Path length. The values observed of the length of a path in a network is the number of links traversed along the path are all of similar size.

3.2 Arable Land and Water-withdrawal

- Arable Land

The data express the total available land per country/continent and per Climate Zone. The total available land is further divided in : arable land which is then divided in land for crops and land for meadows/pastures.

Availability in the future of land for food, feed and animal production, including *pasture*, are increasingly a source of concern.

- The built environment, the absence of sustainable urbanization design leads to uncontrolled expansions diminishing available land reserves for agriculture production.
- Additionally the global warming phenomenon and the resulting climate variability represent important threats for the future generations: soil erosion by extreme weather conditions, storms with flooding of river basins, extension of desertification of entire regions, reduce systematically available land reserves for food production.

On the other side, increasing the efficiency of the food chain -from harvest to dishes- is a way for answering the need for more food, however can it be sufficient? Some authors defend this approach³⁹.

The industrial practice of producing animals in entire artificial environments, as is already the case for pigs and poultry, will give some relieve, however it is a particular solution, which enhances the alienation of humans toward nature and the biosphere. The available land for agriculture is a question to be addressed seriously and is a matter of global governance.

*Forests*⁴⁰. If additional land would be made available through cutting *forests*, as is already practiced for some decades in some continents, modifies in the long run the planetary equilibrium of atmosphere-biosphere, and will lead to irreversible disruptions of the living conditions of the biosphere.

- Fresh Water-withdrawal

Unfortunately in several regions of the planet the surface and freatic water tables are dangerously polluted as well as their quantities are decreasing rapidly, e.g. California, US, producing fresh water for millions inhabitants.

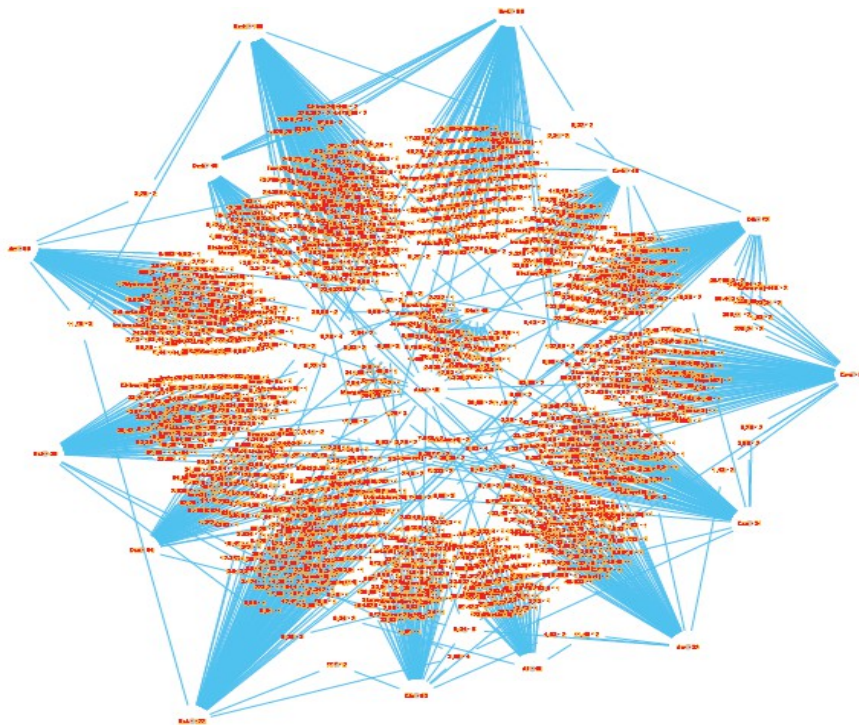
Further, in high mountain regions in Asia, Europe, Latin America, the fresh water availability is increasingly threatened in summer periods, which will be disastrous for food

production, due to lack of fresh water in the warmest and most productive periods of the year, and in densely populated areas.

The populations living along major river basins, mainly but not only in Asia, risk to be severally hit by these phenomena. Some scientists indicate that in the long run, the fresh water availability is by far more critical for the human species than the depletion of fossil energy resources.

In Fig 5 the network is drawn for the Asian Continent (Asia)

Fig 5 Network for the Asian Continent (1053 nodes, 1146 edges)



- Statistical Analysis

The listed characteristics are all mentioned in the ***Gephi*** software. They are based on mathematical analysis and used in the wide variety of networks. The description of these values obtained in the present analysis, are important for positioning the type of network of the research topic.

3.1.3 Entire Terrestrial Planet

The network for all data -population crops, meat, land and water withdrawal- is quite more complex due to the increased number of nodes and edges (4 114 nodes & 6038 edges), but

its structure is similar to the precious ones.

A detailed picture is shown in the Annex Volume and provides a better view of its structure.

- Statistical analysis

In Table 13a are listed the number of nodes and edges for the different continents for Land and Water Withdrawal, as well as their sum as Terrestrial Planet, the last column covers the data of Part I & II of this paper. The graphical representations are all *undirected* and the network design with the algorithms, either *Fruchterman Reingold* or *Force Atlas*.

Table 13a Network size for the different Continents & the Terrestrial Planet
(Population, Land crops & meadows, Water-withdrawal for agriculture)

Network Graphics & Characteristics	Africa Continent	Asia Continent	EUR Continent	N.+M. Am. Continent	South Am. Ocea.Cont.	Terrestrial Planet
Nodes	966	1053	793	450	578	4114
Edges	1049	1146	904	478	664	6038
Ratio. Edges/Nodes	1.086	1.088	1.140	1.062	1.148	1.467

The values of the nodes and edges vary much more than with crops and meat. The ratios are much more similar among the continents, however quite larger for the entire planet. It means that there more links (edges) connected to the nodes.

Table 13b Statistical properties for the Continents & the Terrestrial Planet.
as delivered by *Gephi software*

Statistical Properties & Characteristics	Africa Continent	Asia Continent	EUR Continent	N.+M. Am. Continent	South Am. Ocea.Cont.	Terrestrial Planet
Network Overview						
Average Degree	2.153	2.177	2.28	2.124	2.298	2.48
Aver weighted Degree	2.402	2.414	2.547	2.364	2.526	2.79
Diameter	4	4	4	4	4	6
Graph Density	0.002	0.002	0.003	0.005	0.004	0.001
Modularity						
Size Distribution	0.661	0.746	0.666	0.727	0.709	0.688
Number Connections	8	14	13	13	11	20
Page Rank						
Probability	0.85	0.85	0.85	0.85	0.85	0.85
Node Overview						
Eigenvector Centrality	0.0288	0.045	0.026	0.014	0.031	0.048
Edge Overview						
Aver. Path Lenght	3.636	3.789	3.598	3.628	3.723	3.799

3.2 Programming with *R*

The use of the program language *R*³³ allows the search for the complementary graphical analyses of the network of agriculture production processes. Four specific approaches have been explored : the adjacency matrix calculation, the dendrogram related to the matrices, decision trees and a logarithm relation between CZs and the calculated euclidean distances. The data used are those from Table 5 (p25). The Climate Zones are exclusively used these calculations, they are by far a better more representative for a network analysis.

3.2.1 Adjacency Matrix

An adjacency matrix is a means of representing which nodes of a graph are adjacent to which other nodes. The use of the program language *R* allows a graphical output as shown here. The data from Table 5 (page 24) are used and ordered by CZs for the two identities -crops and meat- and their combination, and land for agriculture and water-withdrawal. The analysis is extended to the quantities per capita.

A *weighted network* is created by assigning a weight to each edge of the network. There is an edge between each two climate zones (in effect creating a fully connected graph) and the weight is calculated as follows :

The items/properties can be interpreted as the coordinates of a point in a 3-dimensional space for crops, 4-dimensional space for meat and 7-dimensional space for crops and meat together for each CZ.

The weight of an edge is then defined as the euclidean distance between those points. The weight thus specifies the difference or dissimilarity in production between the different CZs. The smaller the weight, the more similar the CZ are with respect to the production of crops, meat, or both and the other parameters, land and water-withdrawal.

In order to make the different columns comparable, they are first statistically normalized by converting them to Z-scores (the mean of each column is subtracted from all numbers of that column and then they are divided by the standard deviation of that column). Values lower than -1 and greater than +1 are considered very low and very high values respectively.

The weights are then put in an adjacency matrix and visualized, together with a dendrogram, showing clusters of CZs which are similar to each other. The height of the elements of the dendrograms correspond with the distance between the involved clusters.

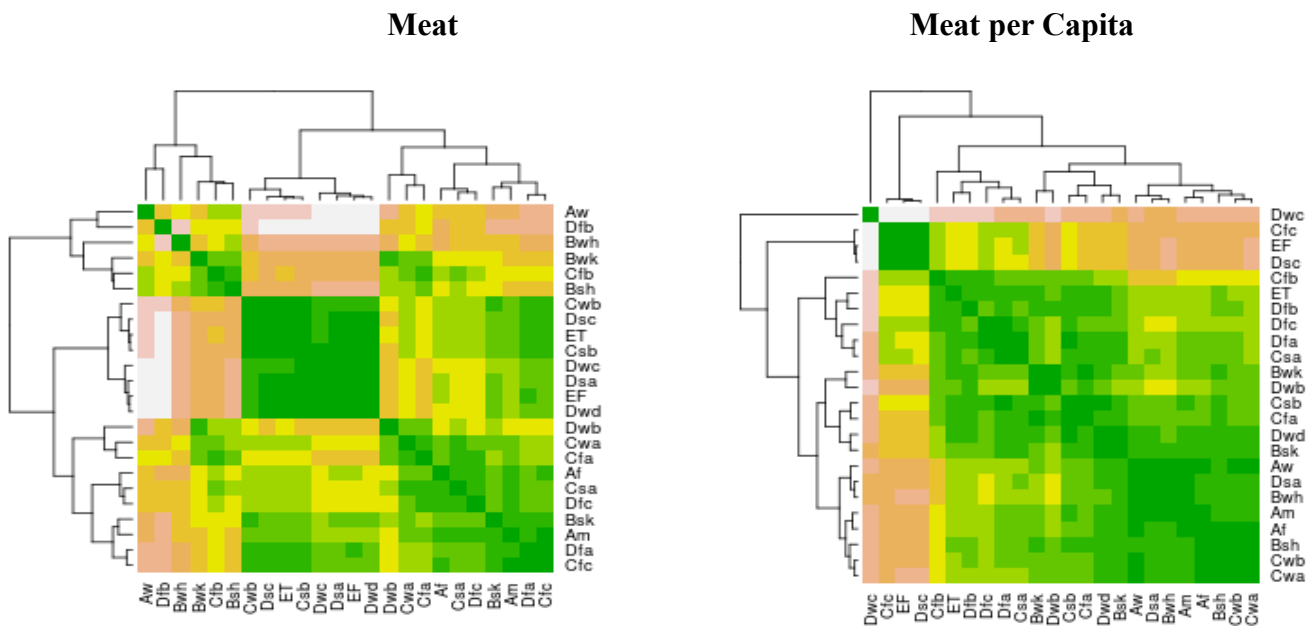
- For **crops**, each CZ has 3 items/properties : the production of rice, wheat and maize.
- For **meat**, the same is done as for crops. In this case the production of beef, pigs, sheep/goat and poultry are used to form points in a 4-dimensional space.
- For **crops and meat**, a network is created for the CZs using the total production, using points in a 7-dimensional space.

In the adjacency matrix diagrams, the CZs are the leading variables and show a *hierarchical clustering structure* or a *dendrogram*³⁴. They illustrate a measure of similarity or connection strength between nodes, based on the network structure and joined together the closest or most similar nodes to form groups, showing some 10 levels of hierarchical structure among the Climate Zones. The CZs involved for each type allows to identify the main production zones for the crops and meat types. The involved countries are identified through the Climate Zones.

With the help of these connectivity pictures it will be possible to extrapolate potential areas for increasing production as well as to diagnose the vulnerability of the zones in respect with climate change resp. variability.

The diagrams in Fig 7 the meat production (tonnes/year) are displayed, as well as per capita (tonnes/year/capita). The graphs show quite a difference in cluster building between meat production and the one per capita. Indeed the CZs combinations differ significantly from each other as it appears in the enumeration of the CZs at both axes. The dendrograms representation at the top and at the left side of these graph show the differences more clearly. Similar calculations have been made for crops and the other parameters and will be presented in VolumeII.

Fig 7 Adjacency Matrix. Meat production



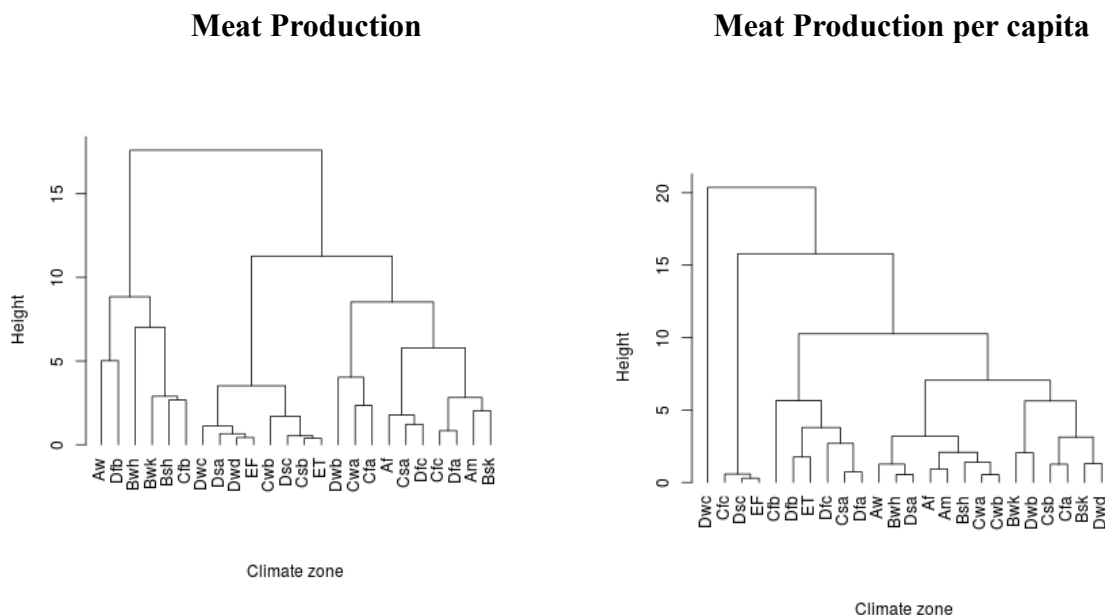
3.2.2 Dendrogram. Meat production.

In a hierarchical cluster tree or dendrogram, any two objects in the original data set are eventually linked together at some level. The height of the link represents the distance between the two clusters that contain those two objects. This height is known as the *cophenetic distance* between the two objects.

A link that is approximately the same height as the links below indicates that there are no distinct divisions between the objects joined at this level of the hierarchy. These links are said to exhibit a *high level of consistency*, because the distance between the objects being joined is approximately the same as the distances between the objects they contain.

On the other hand, a link whose height differs noticeably from the height of the links below it, indicates that the objects joined at this level in the cluster tree are much farther apart from each other than their components are when they were joined. This link is said to be *inconsistent* with the links below it.

Fig 8 Dendrogram Meat production



The interconnections between CZs are quite different in both pictures, indicating the importance of the impact of the population density in a given CZ. This was already in the adjacency matrix of Figure 7.

3.2.3 Decision Tree

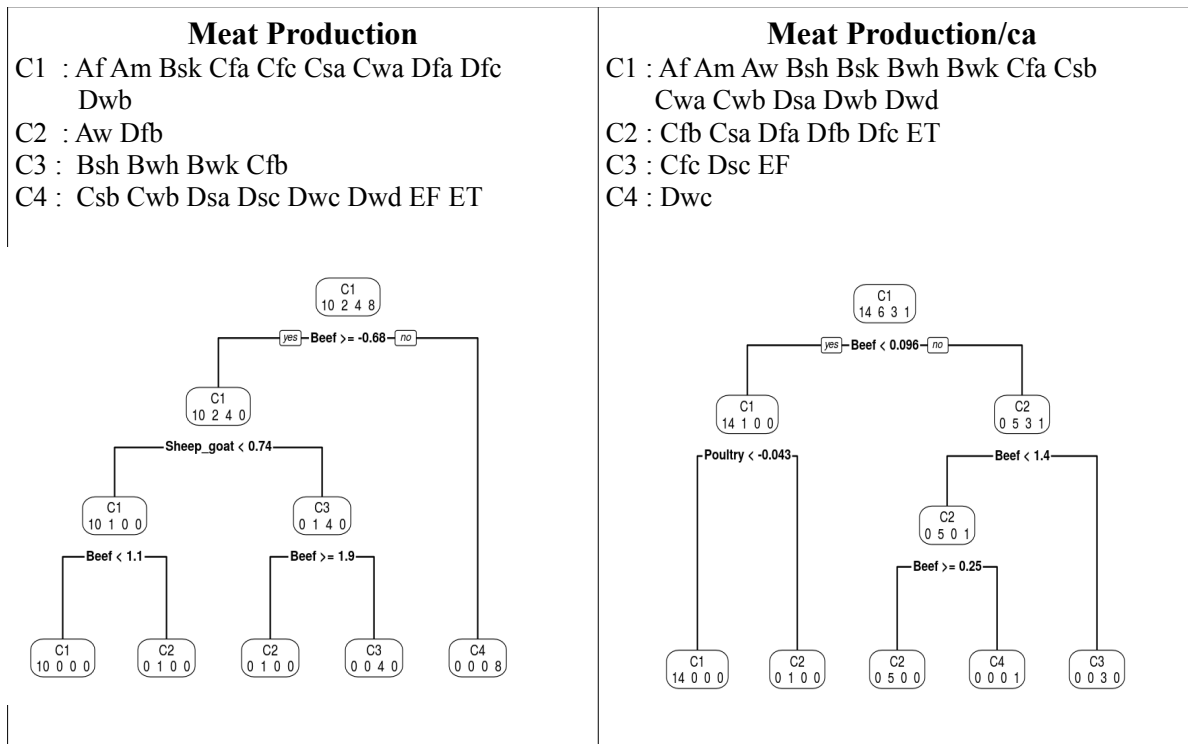
All values used to decide which path to follow in the *decision tree* are normalized values. This means that 0 is the average production and 1 is the standard deviation. The numbers x/x/x/x in the diagram correspond to the amount of CZs in each cluster, their sum is 24 for each level, corresponding to the sum of CZs.

In the calculation of the decision tree four categories have been set forward for grouping the CZs, they are C1 to C4. This allows to visualize the links between CZs inside each parameter, crops, meat, land area and water-withdrawal and their values per capita.

It appears that the production of meat and per capita show quite different profiles as was the case with dendrograms, the differences are related to the population density. The composition of the categories of both decision trees are included in the pictures, they represent a clear aid to the impact of population density of the CZs.

The Figure 9 represents the decision tree for the crops production along the four categories C1-C4 of CZs. The numbers x/x/x/x correspond to number of CZs (24) in each cluster.

Fig 9 Decision tree. Meat production



- Meat Production.

Beef. The first cluster, the production of beef has the value of $C4 \geq -0.68$, this means that the category C1 (to the right of the cluster) has a normalized production of beef lower than -0.68 , which splits up in C1 and C4. Further C1 splits up in C1 and C3 and again in C1, C2 and C3. Each level has the total sum of the CZs.

Sheep-goat. The Sheep-goat production of CZ in C1 is lower than < 0.74 . The tree splits into C1 where beef < 1.1 and C3 with beef ≥ 1.9

Poultry and pigs do not show up in this tree, they are distributed over the four categories.

- Meat production per capita.

The structure of the tree per capita is quite different compared to meat production.

Beef. Beef is again a leading entity with C1 and < 0.096 , this level splits into C1 & C2.

Poultry. Poultry appears in C1 with the value < -0.043 and splits into C1 and C2. Beef remains at the other levels (to the right) with higher values < 1.4 and > 0.25 .

Pigs and Sheep-goat. Do not visible in this tree per capita.

Table 14 Decision Tree. Meat production & per capita C1-C4

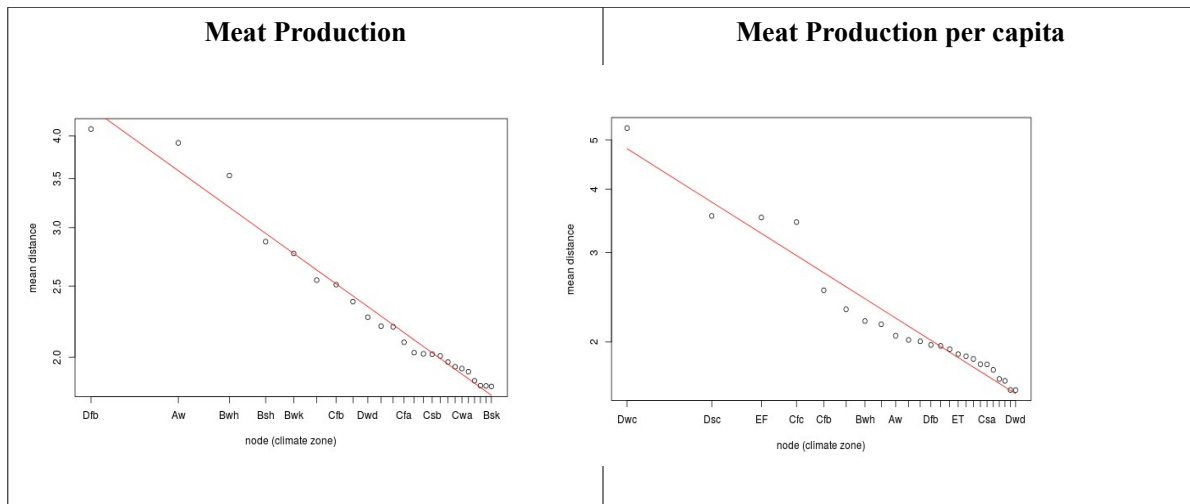
		Meat Production				Meat per Capita			
Category	Population # thous.	Beef	Pigs	Sheep	Poultry	Beef	Pigs	Sheep	Poultry
		10 ³ tons 2010	10 ³ tons 2010	10 ³ tons 2010	10 ³ tons 2010	kg/y/ca	kg/y/ca	kg/y/ca	kg/y/ca
C1	2,792,753	29,041	47,812	4,366	46,951	10.40	17.12	1.56	16.81
C2	1,721,529	14,930	22,336	2,038	21,794	8.67	12.97	1.18	12.66
C3	2,033,322	19,174	32,532	6,314	23,581	9.43	16.00	3.11	11.60
C4	380,464	4,440	6,262	681	6,198	11.67	16.46	1.79	16.29
	6,928,068	67,585	108,942	13,399	98,524	-	-	-	-

3.2.4 Log-Log Plots with R

The Log-Log plots are inspired by the 'powerlaw' relationship found in several large networks, e.g. Internet, metabolism of bacteria, a.o. In the present case the mean distance between nodes -the links- and the node of the climate zones are plotted in logarithmic scales. The higher the mean distance, the less connection of the nodes, on the other hand the closer the distance, the smaller the mean distance, the more numerous the nodes. In Fig 10 the plot represents the relationship for the *meat production*, the others parameters -crops, etc.- show similar relationships, listed in the Annex Volume. In the Table 15 the slopes are listed for all the combinations.

The lower the value of the slope, the better the correlation, as illustrated in Table 15. The ratio of the slopes gives an qualitative picture of the distribution among the populations of the parameters, crops, meat and their combinations.

Fig 10 Log-Log Meat production



The ratio <1 indicates a better distribution among the capita, whereas the values >1 indicate a lower distribution. This seems to be case, in particular, for the combination of Agriculture water (1.273) and for Crops & water (ratio = 1.374).

Table 15 Slopes of the dendrograms

Item	Slope 1	Item/capita	Slope 2	Ratio 1/2
Crops production	-0.272	Crops production/capita	-0.235	1.157
Meat production	-0.283	Meat production/capita	-0.350	0.808
Crops & Meat prod.	-0.255	Crops & Meat prod./ca	-0.267	0.955
Crops & Meadows	-0.421	Crops & Meadows/ca	-0.509	0.827
Agricultural water	-0.415	Agricultural water/capita	-0.326	1.273
Crops & water	-0.426	Crops water/capita	-0.310	1.374

Chapter 4. Evolution up to 2100. CZs and Demography

4.1 IPCC Approaches

In what follows, extensive use has been made from the IPCC reports^{47, 48}.

Climate change refers to a change in the *state of the climate* that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Impacts from recent *climate-related extremes*, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some eco-systems and many human systems to current climate variability. Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being.

Crops. Climate change has negatively affected *wheat and maize* yields for many regions and in the global aggregate. Effects on rice and soybean yield have been smaller in major production regions and globally, with a median change of zero across all available data, which are fewer for soy compared to the other crops. Observed impacts relate mainly to production aspects of food security rather than access or other components of food security.

Freshwater-related risks of climate change increase significantly with increasing GHG (greenhouse gases) concentrations. The fraction of global population experiencing water scarcity and the fraction affected by major river floods increase with the level of warming in the 21st century. Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry sub-tropical regions, intensifying competition for water among sectors.

In presently *dry regions*, drought frequency will likely increase by the end of the 21st century under RCP8.5. In contrast, water resources are projected to increase at high latitudes. Climate change is projected to reduce raw water quality and pose risks to drinking water quality even with conventional treatment, due to interacting factors : increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentration of pollutants during droughts; and disruption of treatment facilities during floods.

Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can help create resilience to uncertain hydrological changes and impacts due to climate change.

The effect of *global warming* and *climate variability* have to be addressed, by scientists, sociologists and decision-makers during the present century. However, a tremendous challenge appears to be the evaluation the quantitative effects due to global warming change within the Climate Zones, as defined by the Köppen-Geiger Classification System. This appears a very difficult endeavor due to lacking of systematic available data.

Therefore the present analysis tries to build a practical synthesis of the effects of global warming on the bio-sphere by the end of this century. A time jump of about one hundred years is proposed being from 1976-2000 to 2076-2100. The effect of global warming over a time span of a century is most likely a too short a period, although some effects are already taken place today.

4.1.1 Emission Scenarios SRES⁴⁷ (2000)

United Nations Framework Convention on Climate Change (UNFCCC), in its Article1, defines climate change as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

The International Panel on Climate Change (IPCC) has over more than 25 years contributed extensively to the understanding of the global warming process. Several climate models have been developed describing possible scenarios how the impact would evolve over long periods up to 2250. Overtime IPCC has used two different modeling approaches : the SRES first described (Special Report on Emission Scenarios, 2000) and RCPs (Representative Concentration Pathways, 2013 in AR5).

By 2100 the world will have changed in ways that are difficult to imagine – as difficult as it would have been at the end of the 19th century to imagine the changes of the 100 years since.

Each *storyline* assumes a distinctly different direction for future developments, such that the four story-lines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key “future” characteristics such as demographic change, economic development, and technological change. For this reason, their plausibility or feasibility should not be considered solely on the basis of an extrapolation of current economic, technological, and social trends.

– The ***A1 storyline*** and scenario family describes a *future world of very rapid economic growth*, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are *convergence among regions, capacity building, and increased cultural and*

social interactions, with a substantial reduction in regional differences in per capita income.

The *A1* scenario family develops into *three groups* that describe alternative directions of technological change in the energy system. The three *A1* groups are distinguished by their technological emphasis:

- *A1FI* fossil intensive,
- *A1T* non-fossil energy sources
- *A1B* balance across all sources

– The ***A2 storyline*** and scenario family describes a *very heterogeneous world*. The underlying theme is *self-reliance and preservation of local identities*. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other story-lines.

– The ***B1 storyline*** and scenario family describes a *convergent world* with the same global population that peaks in mid-century and declines thereafter, as in the *A1* storyline, but with *rapid changes in economic structures toward a service and information economy*, with *reductions in material intensity*, and the introduction of *clean and resource-efficient technologies*. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

- The ***B2 storyline*** and scenario family describes a world in which the emphasis is on *local solutions to economic, social, and environmental sustainability*. It is a world with continuously increasing global population at a rate lower than *A2*, intermediate levels of economic development, and less rapid and more diverse technological change than in the *B1* and *A1* story-lines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels

There are six scenario groups that should be considered equally sound that span a wide range of uncertainty, as required by the Terms of Reference. These encompass four combinations of demographic change, social and economic development, and broad technological developments, corresponding to the four families (*A1*, *A2*, *B1*, *B2*), each with an illustrative “marker” scenario. Two of the scenario groups of the *A1* family (*A1FI*, *A1T*) explicitly explore alternative energy technology developments, holding the other driving forces constant, each with an illustrative scenario. Rapid growth leads to high capital turnover rates, which means that early small differences among scenarios can lead to a large divergence by 2100. Therefore the *A1* family, which has the highest rates of technological change and economic development, was selected to show this effect.

4.1.2 Representative Concentration Pathways RCPs^{48, 49} (2013)

A crucial element of the new scenarios is land use. Land use influences the climate system in many different ways including direct emissions from land-use change, hydrological impacts,

bio-geophysical impacts (such as changes in albedo and surface roughness), and the size of the remaining vegetation stock (influencing CO₂ removal from the atmosphere).

Perhaps the most innovative aspect of the RCPs is that instead of starting with socio-economic ‘story-lines’ from which emission trajectories and climate impacts are projected (the SRES methodology), RCPs each describe an emission trajectory and concentration by the year 2100, and consequent forcing. Each trajectory represents a specific synthesis drawn from the published literature. From this ‘baseline’, researchers can then test various permutations of social, technical and economic circumstances. These permutations are called ‘*narratives*’, equivalent to the ‘*story-lines*’ employed in SRES.

Historically, cropland and anthropogenic use of grassland have both been increasing, driven by rising population and changing dietary patterns. There are far fewer land-use scenarios published in the literature than emission or energy-use scenarios.

The limited experience in global land-use modeling as part of integrated assessment work is also reflected in the RCP development process. Compared to emission modeling, definitions of relevant variables and base year data differ more greatly across the IAMs (Integrated Assessment Models) for the land use components.

Table 16 IPCC-AR5 global warming increase projections (°C)⁵⁰

	2046-2065	2081-2100
Scenario	Mean °C and <i>likely</i> range	Mean °C and <i>likely</i> range
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

The RCPs cover a very wide-range of land-use scenario projections.

RCP8.5. The use of cropland and grasslands increases in RCP8.5, mostly driven by an increasing global population.

RCP2.6. Cropland also increases in the RCP2.6, but largely as a result of bio-energy production. The use of grassland is more-or-less constant in the RCP2.6, as the increase in production of animal products is met through a shift from extensive to more intensive animal husbandry.

RCP6. The RCP6 shows an increasing use of cropland but a decline in pasture. This decline is caused by a similar trend as noted for RCP2.6, but with a much stronger

implementation.

RCP4.5. The RCP4.5 shows a clear turning point in global land use based on the assumption that carbon in natural vegetation will be valued as part of global climate policy”.

4.2 Global Warming effect on Climate Zones (CZ).

Köppen-Geiger's rigid boundary criteria often leads to large discrepancies between climatic subdivisions and features of the natural landscape. In the nature, the division between two climate types can hardly be a sharp cut.

It is well known that the high latitudes, especially the polar regions, have much higher warming than lower latitudes under the influence of the global warming, and the tropical regions experience very small changes according to *Solomon*⁴³, which can explain the small and big changes in A and E respectively.

The expansion of type B is most remarkable, since the area covered by B is the largest and the dry climate represented by B has a significant impact on ecosystems and humans. This type of climate is characterized by the fact that precipitation is less than potential evapo-transpiration. Thus, decreased precipitation in combination with increased temperature (evapo-transpiration) may be the cause for the expansion of type B whose pole-ward boundary is associated with the extension of the *Hadley circulation*⁴⁴ in the tropics.

Showing the changes of all the sub-types in the same way as for the major groups.

- **Class A** [*Tropical/megathermal climate*]. For sub-types under A, the type As stands out as the most variable type.
- **Class B** [*Dry (arid and semi-arid) climate*]. For the dry climate, the identified increase for group B appears to be mainly caused by the increased in Bwh [*warm desert climate*], although other three types also have an overall increasing trend over the last few decades.
- **Class C** [*Temperate/mesothermal*]. For group C, types Cfc [*Cool oceanic climate*] and Csc [*not withheld here*] turn out to be the two most variable types which often have opposite directions in their changes. As a result, the total change in group C is small.
- **Class D** [*Continental/microthermal climate*]. The zone Dwd [*Cold continental climate/sub-arctic climate*] dominates the changes in group D and all other types show relatively small changes compared with those of Dwd. However, the sub-types in group D generally have larger changes than those in other groups.
- **Class E** [*polar and alpine*]. There is almost no change in ET [*tundra*], whereas EF [*icecap*] shows a dramatic change with a two stage decrease that caused the overall decreasing trend for group E. Changes in EF is most likely a manifestation of the enhanced warming in the arctic region under the global warming trend.

According to *Franz Rubel* and *Markus Kottke*⁴⁵ observed **global temperature and precipitation data sets** collected during recent years offer the possibility to compile a 100-years

time series of global maps of Köppen-Geiger climate classification. The observational period was extended by global climate model (GCM) projections to cover the 200-year period 1901–2100.

The projections from 5 GCMs applied to four emission scenarios defined by the IPCC (Intergovernmental Panel on Climate Change) and described in the Special Report on Emission Scenarios (SRES) were used. Unlike previous studies, climate models are not investigated concerning their differences, but they are used to provide ensemble means of global temperature and precipitation distributions to estimate Köppen-Geiger maps of possible future worlds.

Therewith fundamental climate trends become visible. These trends comprise for example :

- the decreased permafrost in high-latitudes of the Northern hemisphere,or,
- the increased aridity in the Mediterranean area in Southern Europe.

Two global data-sets of climate observations were selected to calculate world maps of Köppen-Geiger climate classes. Both are available on a regular 0.5 degree latitude/longitude grid (3,060 km² per 0.5 degree) with monthly temporal resolution.

- The first data-set is provided by the *Climatic Research Unit (CRU)* of the University of East Anglia, UK, and delivers grids of monthly climate observations from meteorological stations comprising nine climate variables from which only the temperature is used in this study.

- The second data-set, provided by the *Global Precipitation Climatology Centre (GPCC)* located at the German Weather Service, is the so-called GPCC's Full Data Re-analysis Version 4 for 1901–2007.

This recently updated grided precipitation data-set covers the global land areas excluding Greenland and Antarctica. Most of the meteorological and hydrological services of the world, as well as the hosts of the global precipitation station data-bases

According to the *OECD-FAO Outlook*⁴⁶ the most visible climate change may be found in the Northern hemispheric 30–80° belt, where B, C, D and E climates successively shifts to the north. The extreme scenarios have been selected to demonstrate climate change. The *AIFI* scenario of the SRES report shows the largest shifts, the *B1* scenario the smallest between the main Köppen-Geiger climate classes. Values for A2 and B2 scenarios are within this range

In the observational period 1976–2000 a total of 29.14 % of the global land area is covered by climates of type B, followed by 21.62 % D climates, 19.42 % A climates, 15.15 % E climates and 14.67 % C climates, respectively.

Assuming an *AIFI* emission scenario for the period 2076–2100, the ensemble mean of the 5 GCM projections results in a coverage of 22.46 % of A climates or an increase of (+3.04 %), 31.82 % of B climates (+2.68 %), 15.20 % of C climates (+ increased0.53 %) as well as

a decreased coverage of 11.04% of E climates (-4.11 %) and 19.48 % of D climates (-2.14 %). Significantly smaller shifts of climate zones were projected for the *B1* emission scenario. Additionally in contrast to an increased coverage projected for the *A1FI* scenario, a decreased coverage of C climates was projected for the B1 scenarios.

Table 17

Climate Class	1976-2000 [<i>A1FI</i>]	2076-2100 [<i>A1FI</i>]	Difference
	%	%	
A	19.42	22.46	+3,04%
B	29.14	31.82	+2,68%
C	14.67	15.2	+0,53%
D	21.62	19.48	-2,14%
E	15.15	11.04	-4,11%
Sum	100	100	0

The shifts between the main climate classes are maximal around the D climates. For example, concerning the *A1FI* emission scenario, the maximum shift was projected from D to C climates (4.67 ± 3.87 %) and for the *B1* emission scenario from E to D (2.60 ± 1.25 %). As for the main climates, the change is maximal for D sub-climates Dfb, Dfc and Dfd. Further climate shifts are visible for example in the tropics, where areas covered by Af and Am climates increase.

According to *Deliang Chen, Hans Weiteng Chen*²⁶ the Köppen-Geiger climate classification scheme provides a framework in which climate is characterized by a number of distinct seasonal temperature and precipitation regimes depending on the combination of seasonal temperature and precipitation.

As climate changes, it is expected that climate types around the boundary between two different types may shift from one regime to another. By examining historic changes using instrumental data and future changes using climate model simulations, a number of studies have confirmed that climate changes are indeed associated with shifts between climate types.

The global climate model projections of future climate around 2050 show that the areas occupied by the climate groups A and B would be larger than the current climate, and the areas for other major climate groups would become smaller. These results are in line with those from *Lohmann et al*²¹. (1993). It should be kept in mind that all mentioned studies look at changes in the Köppen-Geiger climate types on the typical climate time scale, which on average is about 30 years.

Although the Köppen-Geiger scheme was designed to reveal averaged climate in relation to

corresponding vegetation types on Earth, it may also be useful in describing shorter climate variability if the link between climate and vegetation is not a primary concern. Vegetation change would involve a long term adaptation process and short term variation in climate may be irrelevant for vegetation change.

While the usefulness of the Köppen-Geiger classification in describing mean climate conditions -around 30 years and longer- has been widely recognized, the possibility to use the method to characterize climate variability on shorter time scales needs to be explored. *Peel et al.*¹⁹ (2007) show the geographic locations of the stations in GHCN2 (Global Historical Climatology Network, version 2), revealing that the geographic coverage of the stations vary with time and that there are many more temperature stations than precipitation stations. In terms of the percentage of precipitation and temperature stations with a value for a given month, 1900–1970 saw a strong increasing trend (30–90% for both temperature and precipitation stations), while there is a sizable decreasing trend starting from around 1970. Generally speaking, Europe, North America, Japan and eastern Australia have good spatial and temporal coverage, while Africa, the polar regions and some tropical regions have sparse station density and relatively short records.

The authors *Mahlstein, Irina, John S. Daniel, and Susan Solomon*²³ have shown that current climate projections suggest that the pace of shifting climate zones increases approximately linearly with increasing global temperature. Using the RCP8.5 emissions pathway (see below), the pace nearly doubles by the end of this century and about 20% of all land area undergoes a change in its original climate. This implies that species will have increasingly less time to adapt to Köppen-Geiger zone changes in the future, which is expected to increase the risk of extinction.

Among others, *Rubel and Kottek*⁴⁵ used the Köppen-Geiger classification to estimate how large the shifts between the different climate classes are based on climate model simulations. The purpose of the Köppen-Geiger classification system is to predict biome distribution based not only on monthly temperature and precipitation values but also on the annual cycles of both.

This classification also takes into account plant sensitivity to thresholds. Such bio-climatic classification schemes have the advantage that they are easily applied to climate model output, and therefore possible future changes in ecosystem types can be evaluated on a grid cell level as for every grid cell bio-climatic information becomes available.

The authors use the precipitation and temperature changes calculated from historical and RCP8.5 CMIP5 runs to analyze changes in the Köppen-Geiger climate classification at the grid-point level of the simulations for the time period 1900-2098. The Köppen-Geiger scheme is very sensitive to thresholds as it distinguishes between different climates based for example upon whether conditions are warmer than some temperature or wetter than a particular precipitation amount.

Then, for each model and each time step the percentage of land area that changed to a new climate zone is estimated. In determining the percentage of land area that has changed to a new climate zone in a warming world, a change for a particular grid point is counted when a fully distinct new climate zone appears. To reduce the possibility that climate variability might cause calculated climate zone shifts, for each model and grid cell all 'natural' climate zones that are obtained in linearly detrended 5 year running mean data are evaluated before examining future states. Therefore, all changes found are statistically significant, since they are not due to variability.

Novel climates cannot emerge in this study by definition, as all possible combinations of temperature and precipitation will give one of the Köppen-Geiger Climate zones can disappear, but a large perturbation is required. Whether climate zones disappear is highly dependent on the specific climate model.

However, there are some common 21st century changes across all models:

- frost climates are largely decreasing,
- some arid regions are increasing, and,
- a large fraction of the land area changes from cool summers to hot summers.

Almost all land areas of the northern middle and high latitudes undergo climate shifts, whereas the tropical regions do not see many changes. This seems at first glance to be in contradiction to previous findings where temperature increases show the earliest emerging signals in the tropics. However, as the Köppen-Geiger classes are threshold based, and tropical climates already have hot summers, a further increase in temperature generally will not affect the climate class. Precipitation changes would have an impact, but on a grid cell level, these areas show no significant changes in precipitation.

Most changes obtained here seem to be temperature rather than precipitation driven. This finding is supported by doing the same analysis for two cases in which either temperature or precipitation is held fixed over time by linearly detrending that variable. In the case in which precipitation is held constant, the fraction of land area that experiences a change is only slightly smaller. However, when temperature is held constant a much smaller fraction of the land area sees a change. It is interesting to note that when only temperature changes, the increase in area changed seems to be slightly more linear; however when precipitation is allowed to change and temperature is fixed the changes are quadratic. When added together, the results appear to be approximately equal. This suggests that the two signals of temperature and precipitation are not counteracting but complement each other. This is not surprising as the Köppen-Geiger classification is defined such that temperature and precipitation are quantified independently.

There are several reasons why changes in precipitation seem to be less important for the Köppen-Geiger classification scheme. One factor that should be noted is that the models are known to underestimate the observed precipitation trends. Further, the nature of the

definition of the Köppen-Geiger scheme should also be considered. Most wet areas become wetter with future changes and dry places drier.

The thresholds relevant to the KGCCS zones are often defined as a minimal or maximal amount of precipitation, and most regions are above or below the thresholds to start with. For example, if a region is already rated as wet because its precipitation is more than the required amount, a further increase in precipitation often will not lead to a change of Köppen-Geiger climate.

However, it has been suggested that high heat stress could turn tropical regions into uninhabitable regions for mammals. This could start at a global mean temperature increase of 7°C which is larger than the temperature range analyzed here.

It has been shown that the more the global mean temperature increases, the faster land areas face a new climate. Furthermore, climate shifts will happen in some locations below 2°C global temperature increase, and the Earth would be committed to significant impacts due to climate change even if we stabilize CO₂ emissions consistent with the 2°C target.

Climate zones at middle and higher northern latitudes as well as low-latitude mountainous regions and areas in their lee zones are the ones most sensitive to climate changes. The changes in temperature appear to be more important for the overall changes; while this is dependent upon the thresholds that are used in the definitions of Köppen-Geiger zones, the precipitation and temperature thresholds are not arbitrary.

An intermediate conclusion :

Looking into the future concerning the global warming phenomena at planetary scale is quite difficult. The Köppen-Geiger climate system is based on two physical parameters : average ground temperature and precipitations illustrated in Table 1b .

An average increase of ~2°C does not show a shift from one to another zone. Of course the precipitation change has to be added to the increase of the average temperature, but supposes that systematic data are available, which seem not to case for now.

On the other hand an average temperature increase of ~4°C, which is considered to be a possibility by the end of the century, and the correlated precipitation change, although not yet systematically quantified, can lead to changes in the CZ classification.

In the nature, the division between two climate types can hardly be a sharp cut. Thus, the transition zone should be taken separately from the two distinct climate types. It can be considered a fuzzy division between the two. Generally, more unstable regions occur in middle and high latitudes. Relatively speaking, group C now takes the top position in terms of the area variability.

Several studies have examined the changes of the Köppen-Geiger types over the last decades, which revealed a pole ward movement of the Köppen-Geiger climate zones, in

accordance with the global warming. Using a global climate model with changed vegetation types in the arctic region, recently showed that the changed vegetation in the northern high latitudes can trigger a positive feedback in the climate system.

4.3 Demography, Land surface availability per Climate Class and Food availability

4.3.1 Demography. UN data²⁸

The effect of Global Warming and the resulting of the Climate variability, as well as the population increase from ~6,1 billion (2000) to ~9,1 billion (2100) people, are immense challenges for this century. Not only the food production, in its totality, is a big challenge, for it is conditioned by the availability of fresh water for people, vegetation, animal husbandry and the additional land surface for agricultural production, but the demographic evolution with the resulting increased demand for food, in particular of animal husbandry products, due to improved purchase power, has a cumulative effect on the planet's resources.

How the world community will cope with such a demographic increase remains a dramatic question :

- to provide education at all levels
- to provide health-care and hospitals,
- to build shelters and decent housing,
- to build and extend infrastructure for roads, railways and communication, etc.

The situation varies quite differently among the continents. The African continent faces a demographic increase by a factor of 2,83 this century resulting in ~2,25 billion people, which is a much higher increase than the Asian, Northern and Southern American continents. However, the European continent will decrease by 0,25% by 2100.

Historically, humankind has never faced such a magnitude of problems in an extremely limited time span. The impact of the demographic evolution on food requirements, and, extended to the availability of fresh water and land for agriculture, requires to look at the *physical boundaries* of the planet. Indeed, again and again, the knowledge about the physical limits of the eco-bio-system are of existential importance for the survival of the human species, and a threat for the entire bio-sphere.

4.3.2 Land surface availability per Climate Class

The observational period 1976–2000 of the global land area is covered by *Franz Rubel and Markus Kottek*⁴⁵ : most visible climate change may be found in the Northern hemispheric 30–80° belt, where B, C, D and E climates successively shifts to the north.

Table 18

Köppen-Geiger Climate Class	Global land Area Rubel & Kottek 1976-2000 %	IPCC-SRES /A1FI 2076-2100 %	Difference %
A	19.42	22.46	+3.04
B	29.14	31.82	+2.68
C	21.62	15.20	+0.53
D	14.67	19.48	-2.14
E	15.15	11.04	-4.11
SUM	100	100	0

- The emission scenarios **SRES**⁴³, first described *IPCC Special Report Emission Scenarios (2000)* are a set of 'no-climate-policy' options. The A1FI emission scenario, with emphasis on fossil-fuels (Fossil Intensive), for the period 2076–2100, calculates projections results in an increased coverage as illustrated in the above table.

A very important observation has been made by *Deliang Chen & Hans Weiteng Chen*²⁶ indicating that *vegetation* change would involve a long term adaptation process and short term variation in climate may be irrelevant for vegetation change. Obviously for future evaluation about the effects of climate change agriculture output; other parameters like fresh water and arable land availability has to be focused much more strongly.

Another approach with concentration pathways **RCPs** has been introduced in the IPCC-AR5 *Representative Concentration Pathways RCPs*^{48,49}. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values. In RCP8.5, emissions continue to rise throughout the 21st century.

The authors *Mahlstein, Irina et al*²³ have shown that current climate projections suggest that the pace of shifting climate zones increases *approximately linearly* with increasing global temperature. Using the RCP8.5 emissions pathway, the pace nearly doubles by the end of this century, and about 20% of all land area undergoes a change in its original climate. Following these emissions pathway, the mean warming reaches *about 4.5°C* at the end of this century. Model uncertainty however is large, and the different models suggest a range from 17% up to 27% that increases with increasing global average temperature.

A *quadratic increase* of the percentage of land area that changes climate zones leads to two conclusions:

first, there does not appear to be a threshold designated by a step function in the shift of climate zones;

second, the pace of climate shifts increases with increasing mean global temperature.

*Hansen*⁵⁷ also shows that this amount of global temperature increase would lead to

significant climatic changes. However, it can be seen that at 2°C global mean temperature increase nothing extra-ordinary happens. There is for example no step function at 2°C that might suggest that many ecosystems would abruptly become unable to cope with that much warming. Therefore, there is no scientific evidence that 2°C should be a preferred target from a climate zone perspective. Other studies have suggested that the 2°C target does not prevent irreversible changes of the climate.

However, there are some common 21st century changes across all models :

- frost climates are largely decreasing,
- some arid regions are increasing, and,
- a large fraction of the land area changes from cool summers to hot summers.

Almost all land areas of the northern middle and high latitudes undergo climate shifts, whereas the tropical regions do not see many changes. Most wet areas become wetter with future changes and dry places drier. The two major parameters of temperature and precipitation are not counteracting but complement each other. This is not surprising as the Köppen-Geiger classification is defined such that temperature and precipitation are quantified independently.

Chapter 5. Agro-eco system. Diagnosis and Proposals

Food availability is determined by the physical quantities of food that are produced, stored, processed, distributed and exchanged. FAO calculates national food balance sheets that include all these elements. Food availability is the net amount remaining after production, stocks and imports have been summed and exports deducted for each item included in the food balance sheet. Adequacy is assessed through comparison of availability with the estimated consumption requirement for each food item.

5.1 Climate Change And Food Security : A Framework Document^{58, 59}

Production of food and other agricultural commodities may keep pace with aggregate demand, but there are likely to be significant changes in local cropping patterns and farming practices. There has been a lot of research on the impacts that climate change might have on agricultural production, particularly cultivated crops. Some 50% of total crop production comes from forest and mountain ecosystems, including all tree crops, while crops cultivated on open, arable flat land account for only 13 percent of annual global crop production. Production from both rainfed and irrigated agriculture in dryland ecosystems accounts for approximately 25 percent, and rice produced in coastal ecosystems for about 12 percent (Millennium Ecosystem Assessment, 2005).

- *Extreme weather conditions take a toll on crop yields.* Agricultural productivity has improved dramatically over the past 50 years, economists fear that these improvements have begun to wane at a time when food demand, driven by the larger number of people and the growing appetites of wealthier populations, is expected to rise between 70 and 100% during this century. In particular, the rapid increases in *rice* and *wheat* yields that helped feed the world for decades are showing signs of slowing down, and production of cereals will need to more than double by 2050 to keep up. If the trend continues, production might be insufficient to meet demand unless we start using significantly more land, fertilizer, and water.

Climate change is likely to make the problem far worse, bringing higher temperatures and, in many regions, wetter conditions that spread infestations of disease and insects into new areas. Drought, damaging storms, and very hot days are already taking a toll on crop yields, and the frequency of these events is expected to increase sharply as the climate warms. For farmers, the effects of climate change can be simply put : the weather has become far more unpredictable, and extreme weather has become far more common.

CIMMYT. International Maize and Wheat Improvement Center⁵⁴, El Batán, Mexico. The core of CIMMYT consists in two main programs: the Global Wheat Program and the Global Maize Program. Both programs specialize in breeding varieties of their respective crop that are high yielding and adapted to withstand specific environmental constraints, such as infertile soils, drought, insects, and diseases. Center scientists use, traditional cross-breeding, molecular markers, and potentially genetic engineering to develop new varieties.

Additional efforts focus on a variety of agricultural aspects such as proper seed storage, natural resource management, value chains, the benefits of using improved seed, and appropriate machine use and access.

The central highlands of Mexico, for example, experienced their driest and wettest years on record in 2011 and 2012; such variation is worrisome and very bad for agriculture. It is extremely challenging to breed for it, with a relatively stable climate, the breeding is straightforward of crops with genetic characteristics that follow a certain profile of temperatures and rainfall. However, in case of extreme weather variability it is much more difficult to know what traits to target.

According to Oxfam⁵⁵, the total number of natural disasters worldwide now averages 400–500 a year, up from an average of 125 in the early 1980s. The number of climate-related disasters, particularly floods and storms, is rising far faster than the number of geological disasters, such as earthquakes. Between 1980 and 2006, the number of floods and cyclones quadrupled from 60 to 240 a year while the number of earthquakes remained approximately the same, at around 20 a year. Population increases, especially in coastal areas, where most of the world's population now lives, mean that more and more people will be affected by catastrophic weather events.

The impact of global warming on the agriculture production is a difficult matter. In the Köppen-Geiger classification has been introduced two major parameters related to vegetation : temperature and precipitation. These parameters are listed in the Table 2 and refer to the today's situation. The problem lies in the fact to estimate their quantitative effect up to the end of this century.

~2°C. For the major crops (wheat, rice, and maize) in tropical and temperate regions, climate change, without adaptation, is projected to have a negative impact on production for local temperature increases of 2°C or more (compared with the end of the previous century levels), although individual locations may benefit.

Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of the projections for the *period 2030–2049* showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century.

Period after 2050, the risk of more severe yield impacts increases and depends on the level of warming. Climate change is projected to progressively increase inter-annual variability of crop yields in many regions. These projected impacts will occur in the context of rapidly rising crop demand. All aspects of food security are potentially affected by climate change, including food access, utilization, and price stability.

~4°C. Global temperature increases of ~4°C or higher, combined with increasing food demand, would pose large risks to food security globally and regionally. Risks to food security are generally greater in low-latitude areas.

Major future rural impacts are expected in the near term and beyond, through impacts on water availability and supply, food security, and agricultural incomes, including shifts in production areas of food and non-food crops across the world. These impacts are expected to disproportionately affect the welfare of the poor in rural areas, such as female-headed households and those with limited access to land, modern agricultural inputs, infrastructure and education.

*Lobell and Wolfram Schlenker*⁵⁶, an economist at Columbia University, have found evidence that in the case of several important crops, the negative effect of global warming is more strongly tied to the number of extremely hot days than to the rise in average temperatures over a season. If that's true, earlier research might have severely underestimated the impact of climate change by looking only at average temperatures. *Schlenker's* calculations show steady increases in *corn* and *soybean* yields as the temperature rises from 10°C into the 20s -but at around 29°C for corn and 30°C for soybeans, the crops are "hit hard" and yields drop dramatically.

5.1.1 A critical resource : Fresh Water

Managing agricultural water more efficiently is a challenge, even without climate change : the global water economy is already in trouble. A major study, *Water for food, water for life*⁵⁹ reveals that one in three people today face water shortages.

- Water availability per continent

By 2020, between 75 million and 250 million people are projected to be exposed to increased water stress due to climate change. If coupled with increased demand, this will adversely affect livelihoods and exacerbate water-related problems.

Africa^{48,49}. Agricultural production, including access to food, in many African countries and regions is projected to be severely compromised by climate variability and change. The area suitable for agriculture, the length of growing seasons and yield potential, particularly along the margins of semi-arid and arid areas, are expected to decrease. This would further adversely affect food security and exacerbate malnutrition in the continent. In some countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020.

Asia. Glacier melt in the Himalayas is projected to increase flooding, and rock avalanches from destabilized slopes, and to affect water resources within the next two to three decades. This will be followed by decreased river flows as the glaciers recede.

Central, South, East and South-East Asia. Freshwater availability in particularly in large river basins, is projected to decrease due to climate change which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by the 2050s. Climate change is projected to impinge on the sustainable development of most developing countries of Asia, as it compounds the pressures on natural resources and the environment associated with rapid urbanization,

industrialization, and economic development.

It is projected that crop yields could increase up to 20% in East and South-East Asia while they could decrease up to 30% in Central and South Asia by the mid-21st century. Taken together, and considering the influence of rapid population growth and urbanization, the risk of hunger is projected to remain very high in several developing countries.

Europe. For the first time, wide-ranging impacts of changes in current climate have been documented : retreating glaciers, longer growing seasons, shift of species ranges, and health impacts due to a heatwave of unprecedented magnitude. The observed changes described above are consistent with those projected for future climate change. It is expected to magnify regional differences in Europe's natural resources and assets.

Negative impacts will include increased risk of inland flash floods, and more frequent coastal flooding and increased erosion (due to storminess and sea-level rise). The great majority of organisms and ecosystems will have difficulty adapting to climate change. Mountainous areas will face glacier retreat, reduced snow cover and extensive species losses (in some areas up to 60% under high emission scenarios by 2080).

- In *Southern Europe*, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydro-power potential and, in general, crop productivity. It is also projected to increase health risks due to heat waves, and the frequency of wildfires.
- In *Central and Eastern Europe*, summer precipitation is projected to decrease, causing higher water stress. Health risks due to heat waves are projected to increase. Forest productivity is expected to decline and the frequency of peatland fires to increase.
- In *Northern Europe*, climate change is initially projected to bring mixed effects, including some benefits such as reduced demand for heating, increased crop yields and increased forest growth. However, as climate change continues, its negative impacts (including more frequent winter floods, endangered ecosystems and increasing ground instability) are likely to outweigh its benefits. Climate change is causing permafrost warming and thawing in high latitude regions and in high-elevation regions.

North America. Warming in western mountains is projected to cause decreased snow-pack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources. Disturbances from pests, diseases and fire are projected to have increasing impacts on forests, with an extended period of high fire risk and large increases in area burned.

Moderate climate change in the early decades of the century is projected to increase aggregate yields of rain-fed agriculture by 5-20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources.

Latin America. By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazon. Semi-arid vegetation will tend to be replaced by arid-land vegetation. There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America.

In drier areas, climate change is expected to lead to salinization and desertification of agricultural land. Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.

Although there is theoretically sufficient freshwater to meet all the world's projected needs for the foreseeable future, water is not necessarily accessible in the locations where it is needed. Unsustainable use -with use rates exceeding recharge rates- is putting additional pressure on available supplies in many parts of the world. One important reason for this is the increased per capita demand for water that accompanies modern life styles.

The water needs of a single human being grow exponentially as that person's wealth and position in life increase. Each person requires a mere 2 to 5 litres of water a day for survival, and from 20 to 50 litres for cooking, bathing and cleaning. In urban areas worldwide, includes all uses of running water in and around the home, plus other withdrawals from city water supplies for use by public or commercial proper-ties. Without water, people cannot produce the food they eat.

FAO estimates that it takes an average of about 1,000 to 2,000 litres of water to produce 1 kg of irrigated wheat and 13,000 to 15,000 litres to produce the same quantity of grain-fed beef. Thus, each human being "eats" an average of 2 000 litres of water a day. Water use has been growing at more than twice the rate of population increase in the last century, and although there is no global water scarcity as such, an increasing number of regions are chronically short of water. As the world population continues to increase, and rising incomes and urbanization cause food habits to change towards richer and more varied diets, even greater quantities of water will be required to guarantee food security.

Water scarcity is being exacerbated by climate change, especially in the driest areas of the world, which are home to more than 2 billion people, including half of the world's poor. Climate change is expected to account for about 20 percent of the global increase in water scarcity, and countries that already suffer from water shortages will be hit hardest. Even the increasing interest in bio-energy, created by the need to reduce the carbon emissions that cause global warming, could increase the burden on scarce water resources.

Although precipitation is projected to increase at the global level, this will not necessarily lead to increased availability of water where it is needed. In fact, FAO's 2015/2030 projections, citing a 1999 *Hadley Centre* report, state that "substantial decreases are projected for Australia, India, southern Africa, the Near East/North Africa, much of Latin America and parts of Europe".

Currently, about 2 million hectares are irrigated by reused waste-water, but this area could grow. In the longer term, a transition towards more precision-irrigated agriculture should be

anticipated. Conservation agriculture, precision-irrigated agriculture and the resulting improved water productivity, require specialized tools and equipment; incentives are needed to ensure that these inputs are adopted in areas where the expansion of commercial agricultural is desirable.

Is there enough land, water, and human capacity to produce food for a growing population over the next 50 years -or will we “run out” of water? It is possible to produce the food -but it is probable that today’s food production and environmental trends, if continued, will lead to crises in many parts of the world. Only if we act to improve water use in agriculture will we meet the acute freshwater challenges facing humankind over the coming 50 years.

Fifty years ago the world had fewer than half as many people as it has today. They were not as wealthy. They consumed fewer calories, ate less meat, and thus required less water to produce their food. The pressure they inflicted on the environment was lower. They took from our rivers a third of the water that we take now.

Today the competition for scarce water resources in many places is intense. Many river basins do not have enough water to meet all the demands -or even enough for their rivers to reach the sea. Further appropriation of water for human use is not possible because limits have been reached and in many cases breached. Basins are effectively “closed,” with no possibility of using more water.

The lack of water is thus a constraint to producing food for hundreds of millions of people. Agriculture is central in meeting this challenge because the production of food and other agricultural products takes 70% of the freshwater withdrawals from rivers and groundwater.

75% of the additional food we need over the next decades could be met by bringing the production levels of the world’s low-yield farmers up to 80% of what high-yield farmers get from comparable land. Better water management plays a key role in bridging that gap. The greatest potential increases in yields are in rainfed areas, where many of the world’s poorest rural people live and where managing water is the key to such increases. Only if leaders decide to do so will better water and land management in these areas reduce poverty and increase productivity.

While there will probably be some need to expand the amount of land we irrigate to feed >9 billion people, and while we will have to deal with the associated adverse environmental consequences, with determined and focused change there is real scope to improve production on many existing irrigated lands. Doing so would lessen the need for more water in these areas and for even greater expansion of irrigated land.

In *South Asia* -where more than half the crop area is irrigated and productivity is low-with determined policy change and robust institutions almost all additional food demand could be met by improving water productivity in already irrigated crop areas.

In *rural Sub-Saharan Africa* comprehensive water management policies and sound

institutions would spur economic growth for the benefit of all. And despite the bad news about groundwater depletion, there is still potential in many areas for highly productive pro-poor groundwater use, for example, the lower Gangetic plains and parts of Sub-Saharan Africa.

To produce enough food to satisfy a person's daily dietary needs takes about 3,000 liters of water converted from liquid to vapor—about 1 liter per calorie. Only about 2–5 liters of water are required for drinking. In the future more people will require more water for food, fiber, industrial crops, livestock, and fish. But the amount of water per person can be reduced by changing what people consume and how they use water to produce food.

About 80% of agricultural evapo-transpiration -when crops turn water into vapor- comes directly from rain, and about 20% from irrigation. Arid areas like the Middle East, Central Asia, and the western US tend to rely on irrigation. There has also been large-scale irrigation development in South and East Asia, less in Latin America, and very little in Sub-Saharan Africa.

Water-withdrawals are resp. by agriculture (70%), industry (20%), and municipalities (10%). Considering the use of water from rivers, lakes, and groundwater -blue water, the total global freshwater withdrawals are estimated at 3,800 cubic kilometers, with 2,700 cubic kilometers (or 70%) for irrigation, with huge variations across and within countries. Industrial and domestic use is growing relative to that for agriculture. And water for energy generation -hydro-power and thermocooling- is growing rapidly. Not all water withdrawn is “lost.” Much is available for reuse in river basins, but often its quality is degraded.

A growing population is a major factor behind today's water scarcity, but the main reasons for water problems are lack of commitment and targeted investment, insufficient human capacity, ineffective institutions, and poor governance.

Without better water management in agriculture the Millennium Development Goals for poverty, hunger, and a sustainable environment cannot be met. Access to water is difficult for millions of poor women and men for reasons that go beyond the physical resource base. In some places water is abundant, but getting it to people is difficult because of lack of infrastructure and because of restricted access as a result of political and socio-cultural issues.

Water scarcity, defined in terms of access to water, is a critical constraint to agriculture in many areas of the world. A fifth of the world's people, more than 1.2 billion, live in areas of physical water scarcity, lacking enough water for everyone's demands. About 1.6 billion people live in water-scarce basins, where human capacity or financial resources are likely to be insufficient to develop adequate water resources. Behind today's water scarcity lie factors likely to multiply and gain in complexity over the coming years. A growing population is a major factor, but the main reasons for water problems lie elsewhere -lack of commitment to water and poverty, inadequate and inadequately targeted investment, insufficient human capacity, ineffective institutions, and poor governance.

Climate change policy is increasingly supporting greater reliance on bio-energy as an alternative to fossil fuel-based energy. But this is not consistently coupled with the water discussion. The Comprehensive Assessment estimates that with heavy reliance on bio-energy the amount of agricultural evapo-transpiration in 2050 to support increased bio-energy use will be about what is depleted for all of agriculture today. Reliance on bio-energy will further intensify competition for water and land, so awareness of the “double-edged” nature of bio-energy needs to be raised.

Climate change will affect all facets of society and the environment, directly and indirectly, with strong implications for water and agriculture now and in the future. The climate is changing at an alarming rate, causing temperature rise, shifting patterns of precipitation, and more extreme events.

Agriculture in the subtropics -where most poor countries are situated- will be affected most. The future impacts of climate change need to be incorporated into project planning, with behavior, infrastructure, and investments all requiring adjusting to adapt to a changing set of climate parameters.

Water storage and control investments will be important rural development strategies to respond to climate change. The impacts of policies and laws set up to reduce green-house gas emissions or adjust to a changing climate also need to be taken into account.

Per capita food supply in *OECD* (Organization for Economic Co-operation and Development) countries will level off well above 2,800 kcal, which is usually taken as a threshold for national food security. People in low- and middle-income countries will substantially increase their calorie intake, but a significant gap between poor and rich countries will likely remain in the coming decades.

Producing meat, milk, sugar, oils, and vegetables typically requires more water than producing cereals -and a different style of water management. Increasing livestock production requires even more grain for feed, leading to a 25% increase in grains. Thus, diets are a significant factor in determining water demands.

While feed-based meat production may be water costly, grazing systems behave quite differently. From a water perspective grazing is probably the best option for large land areas, but better grazing and watering practices are needed.

Without further improvements in water productivity or major shifts in production patterns, the amount of water consumed by evapo-transpiration in agriculture will increase by 70%–90% by 2050.

The total amount of water evaporated in crop production would amount to 12,000–13,500 cubic kilometers, almost doubling the 7,130 cubic kilometers of today. This corresponds to an average annual increase of 100–130 cubic kilometers, almost three times the volume of water supplied to Egypt through the High Aswan Dam every year.

On top of this is the amount of water needed to produce fiber and biomass for energy. Cotton demand is projected to grow by 1.5% annually, and demand for energy seems insatiable. By

2030 world energy demand will rise by 60%, two-thirds of the increase from developing countries, some from bio-energy.

Under optimistic assumptions about water productivity gains, three-quarters of the additional food demand can be met by improving water productivity on existing irrigated lands.

- In *South Asia* -where more than 50% of the cropped area is irrigated and productivity is low- additional food demand can be met by improving water productivity in irrigated agriculture rather than by expanding the area under production.

- In parts of *China* and *Egypt* and in developed countries, yields and water productivity are already quite high, and the scope for further improvements is limited. In many rice-growing areas water savings during the wet season make little sense because they will not be easily available for other uses.

An alternative strategy is to continue expansion of irrigated land because it provides access to water to more people and can provide a more secure food future. Irrigation could contribute 55% of the total value of food supply by 2050. But that expansion would require 40% more withdrawals of water for agriculture, surely a threat to aquatic ecosystems and capture fisheries in many areas.

- In *Sub-Saharan Africa* there is very little irrigation, and expansion seems war-ranted. 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.

It is time to abandon the obsolete divide between irrigated and rainfed agriculture. In the new policy approach rainfall will be acknowledged as the key freshwater resource, and all water resources, green and blue, will be explored for livelihood options at the appropriate scale for local communities.

Also to be considered is the role of marginal-quality water in improving livelihoods. Rather than thinking of the water flowing out of cities as waste, it needs to be seen as a resource for many poor urban or peri-urban farmers.

We need to consider agriculture as an ecosystem and to recognize the importance of preserving the natural resource base on which agricultural productivity rests. And we need to be cautious in using resources : over-pumped aquifers and over-developed river basins are showing their limits, presenting a different set of problems.

5.1.2 Effects on Crops & Livestock Production

Crops. Food and feed crop demand will nearly double in the coming 50 years. The two main factors driving how much more food we will need are population growth and dietary change. With rising incomes and continuing urbanization, food habits change toward more nutritious and more varied diets -not only toward increasing consumption of staple cereals but also to a shift in consumption patterns among cereal crops and away from cereals toward livestock and fish products and high-value crops.

Africa. FAO projects that the impact of climate change on global crop production will be slight up to 2030. After that year, however, widespread declines in the extent and potential productivity of cropland could occur, with some of the severest impacts likely to be felt in the currently food-insecure areas of sub-Saharan Africa, which have with the least ability to adapt to climate change or to compensate through greater food imports. In Africa, droughts can have severe impacts on livestock, droughts increased livestock mortality in selected African countries between 1980 and 1999.

- The World Food Situation FAO⁵⁹

World. The world **cereal** (e.g. maize, wheat, rice barley, sorghum, millet, rye and oats) production in 2014 is estimated to reach 2,498 billion tonnes, up by 18.0 million tonnes, from the earlier estimate in June, but still 23,0 mio tonnes or 2.2% that of the record production in 2013. The upward revision is mainly due to improved production prospects in coarse grains and wheat crops in the US, EU and India.

Global **wheat** production is anticipated to reach 707.2 mio tonnes in 2014, a decrease of 9.7 mio tonnes (1.4 %) compared with 2013, but still the second largest harvest ever. Most of the reduction in wheat production is accounted for in Canada, with smaller harvests expected in Australia, Morocco, the Syrian Arab Republic, the Russian Federation, Ukraine, and the United States. In contrast, a number of other major producing countries: Argentina, Brazil, India, Mexico and Pakistan are likely to harvest more wheat.

Table 19

Crops Type	Amounts 2014	Comparison with top year 2013
Cereal	2,498 billion tonnes up by 18.0 million tonnes	a decrease of 23,0 mio tonnes 2.2%
Wheat	707.2 mio tonnes in 2014	a decrease of 9.70 mio tonnes (1.4 %)
Coarse grains	1,287.3 mio tonnes	a decrease of 19.0 mio tonnes
Rice	503.6 mio tonnes	up 1.2%

World production of **coarse grains** (e.g. cereals without wheat and rice) is projected at 1,287.3 mio tonnes in 2014, down 19,0 mio tonnes (or 1.5%) from 2013. The anticipated fall is mainly attributed to a smaller production in the United States.

The global **rice** production is estimated at (milled basis) in 2014, from the 2013 level. This increase is despite less attractive prices for rice and a possible recurrence of an El Niño weather anomaly, which is likely to influence the production in Asia. Increases in production are expected in Africa and the Americas.

For climate variables such as rainfall, soil moisture, temperature and radiation, crops have thresholds beyond which growth and yield are compromised. For example, cereals and fruit tree yields can be damaged by a few days of temperatures above or below a certain threshold.

In the European heat wave of 2003, when temperatures were 6°C above long term means, crop yields dropped significantly, such as by 36 percent for maize in Italy, and by 25 percent for fruit and 30% for forage in France (IPCC, 2007c). Increased intensity and frequency of storms, altered hydrological cycles, and precipitation variance also have long term implications on the viability of current world agro-ecosystems and future food availability.

- **Livestock.** In its publication of FAO³⁶ (2006) points out that approximately 70% of the world's agricultural land is used by the livestock sector, including grazing land and cropland for feed production. Current prices of land, water and feed do not reflect true scarcities, leading to the overuse of resources and major inefficiencies in the livestock sector. Full-cost pricing of inputs and widespread adoption of improved land management practices by both intensive and extensive livestock producers would help to resolve more sustainably the competing demands for animal food products and environmental services.

Increased intensification and industrialization are improving efficiency and reducing the land area required for livestock production, but they are also marginalizing small-holders and pastoralists, increasing inputs and wastes and concentrating the resultant pollution. Extensive grazing still occupies and degrades vast areas of grassland.

Overgrazing is the greatest cause of grassland degradation, an important contributor to deforestation and the overriding human-influenced factor in determining soil carbon levels of grasslands. In many systems, improved grazing management, such as optimized stock numbers and rotational grazing, will therefore result in substantial increases in carbon pools. Improved pasture management and integrated agro-forestry systems that combine crops, grazing lands and trees in ecologically sustain-able ways are also effective in conserving the environment and mitigating climate change, while providing more diversified and secure livelihoods for inhabitants.

Livestock's long shadow. LEAD & FAO⁷⁰. The report *Livestock's long shadow* aims to assess the full impact of the livestock sector on environmental problems, along with potential technical and policy approaches to mitigation. The assessment is based on the most recent and complete data available, taking into account direct impacts, along with the impacts of feed-crop agriculture required for livestock production.

The livestock sector emerges as one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global. The findings of this report suggest that it should be a major policy focus when dealing with problems of land degradation, climate change and air pollution, water shortage and water pollution and

loss of biodiversity.

Livestock's contribution to environmental problems is on a massive scale and its potential contribution to their solution is equally large. The impact is so significant that it needs to be addressed with urgency. Major reductions in impact could be achieved at reasonable cost.

Although economically not a major global player, the livestock sector is socially and politically very significant. It accounts for 40% of agricultural gross domestic product. It employs 1.3 billion people and creates livelihoods for one billion of the world's poor. Livestock products provide one-third of humanity's protein intake, and are a contributing cause of obesity and a potential remedy for undernourishment.

Growing populations and incomes, along with changing food preferences, are rapidly increasing demand for livestock products, while globalization is boosting trade in livestock inputs and products. Global production of meat is projected to more than double from 229 mio tonnes in 1999/01 to 465 mio tonnes in 2050, and that of milk to grow from 580 to 1,043 million tonnes. The environmental impact per unit of livestock production must be cut by half, just to avoid increasing the level of damage beyond its present level.

Extensive grazing still occupies and degrades vast areas of land; though there is an increasing trend towards intensification and industrialization. Livestock production is shifting geographically, first from rural areas to urban and peri-urban, to get closer to consumers, then towards the sources of feed-stuff, whether these are feed-crop areas, or transport and trade hubs where feed is imported.

The livestock sector is by far the single largest anthropogenic user of land. The total area occupied by grazing is equivalent to 26 percent of the ice-free terrestrial surface of the planet. In addition, the total area dedicated to feed-crop production amounts to 33 percent of total arable land. In all, livestock production accounts for 70% of all agricultural land and 30 percent of the land surface of the planet.

Expansion of livestock production is a key factor in deforestation, especially in Latin America where the greatest amount of deforestation is occurring - 70% of previous forested land in the Amazon is occupied by pastures, and feed-crops cover a large part of the remainder. About 20% of the world's pastures and rangelands, with 73% of rangelands in dry areas, have been degraded to some extent, mostly through over-grazing, compaction and erosion created by livestock action. The dry lands in particular are affected by these trends, as livestock are often the only source of livelihoods for the people living in these areas.

The livestock sector is a major player, responsible for 18% of GHG emissions measured in CO₂ equivalent. This is a higher share than transport.

The world is moving towards increasing problems of freshwater shortage, scarcity and depletion, with 64 percent of the world's population expected to live in water-stressed basins by 2025. The livestock sector is a key player in increasing water use, accounting for over 8% of global human water use, mostly for the irrigation of feed-crops. It is probably the largest

sectoral source of water pollution, contributing to eutrophication, “dead” zones in coastal areas, degradation of coral reefs, human health problems, emergence of anti-biotic resistance and many others.

The major sources of pollution are from animal wastes, antibiotics and hormones, chemicals from tanneries, fertilizers and pesticides used for feed-crops, and sediments from eroded pastures. Global figures are not available but in the United States, with the world’s fourth largest land area, livestock are responsible for an estimated 55% of erosion and sediment, 37% of pesticide use, 50% of antibiotic use, and a third of the loads of nitrogen and phosphorus into freshwater resources.

We are in an era of unprecedented threats to biodiversity. The loss of species is estimated to be running 50 to 500 times higher than background rates found in the fossil record. Fifteen out of 24 important ecosystem services are assessed to be in decline.

Livestock now account for about 20% of the total terrestrial animal biomass, and the 30% of the earth’s land surface that they now preempt was once habitat for wildlife. Indeed, the livestock sector may well be the leading player in the reduction of biodiversity, since it is the major driver of deforestation, as well as one of the leading drivers of land degradation, pollution, climate change, over-fishing, sedimentation of coastal areas and facilitation of invasions by alien species. In addition, resource conflicts with pastoralists threaten species of wild predators and also protected areas close to pastures. Meanwhile in developed regions, especially Europe, pastures had become a location of diverse long-established types of ecosystem, many of which are now threatened by pasture abandonment.

5.2 Feeding the World Population : feasible options

According to *David Rotman*⁶⁰ Climate change will make it increasingly difficult to feed the world. Biotech crops will have an essential role in ensuring that there’s enough to eat.

5.2.1 Breeding. The work by *Norman Borlaug*^{62, 63}

Norman Borlaug introduced several revolutionary innovations.

-First, he and his colleagues laboriously crossbred thousands of wheat varieties from around the world to produce some new ones with resistance to rust, a destructive plant pest; this raised yields 20% to 40%.

-Second, he crafted so-called dwarf wheat varieties, which were smaller than the old shoulder-high varieties that bent in the wind and touched the ground (thereby becoming unharvested); the new waist or knee-high dwarfs stayed erect and held up huge loads of grain. The yields were boosted even further.

-Third, he devised an ingenious technique called “shuttle breeding”-growing two successive plantings each year, instead of the usual one, in different regions of Mexico. The availability of two test generations of wheat each year cut by half the years required for breeding new varieties.

Moreover, because the two regions possessed distinctly different climatic conditions, the resulting new early-maturing, rust-resistant varieties were broadly adapted to many latitudes, altitudes and soil types. This wide adaptability, which flew in the face of agricultural orthodoxy, proved invaluable, and Mexican wheat yields skyrocketed.

From 1950 to 1992, the world's grain output rose from 692 million tons produced on 0,69 billion ha (1,70 billion acres) of cropland to 1,9 billion tons on 0,70 billion ha (1,73 billion acres) of cropland -an extraordinary increase in yield per ha, being resp. 1,00 ton/ha and 2.70 ton/ha..

India is an excellent case in point. In pre-Borlaug, wheat grew there in sparse, irregular strands, was harvested by hand, and was susceptible to rust disease. The maximum yield was 898 kg per ha (800 lb per acre). By 1968, thanks to Borlaug's varieties, the wheat grew densely packed, was resistant to rust, and the maximum yield had risen to 6736 kg per ha (6000 lb per acre).

How successful were Borlaug's efforts? From 1950 to 1992, the world's grain output rose from 692 million tons produced on 0,69 billion ha (1,70 billion acres) of cropland (1,003 ton/ha) to 1.9 billion tons on 0,70 billion ha (1,73 billion acres) of cropland (2.71 ton/ha -an extraordinary increase in yield of more than 150 percent.

Without high-yield agriculture, either millions would have starved or increases in food output would have been realized only through drastic expansion of land under cultivation -with losses of pristine wilderness far greater than all the losses to urban, suburban and commercial expansion.

5.2.2 Photosynthesis C3 & C4^{64, 65} . The case of Rice

Adapting crops cannot be separated from other management options within agro-eco-systems; for example :

Rice is both affected by and has an effect on Climate change. The latter is expected to have a significant impact on the productivity of rice systems, and thus on the nutrition and livelihood of millions of people. Rice systems, especially in south and east Asia, are under increasing pressure because of their high water needs and their role as a source of methane emissions. New crop management systems are therefore required that increase rice yields and reduce production costs by enhancing the efficiency of input application, increasing water use efficiency, and reducing greenhouse gas emissions.

Rice is currently the staple food of more than half the world's population. In Asia alone, more than 2 billion people obtain 60 to 70% of their calories from rice and its products. It is the most rapidly growing source of food in Africa, and is of significant importance to food security in an increasing number of low-income, food-deficit countries. Rice-based

production systems and their associated post-harvest operations employ nearly 1 billion people in rural areas of developing countries.

About 80% of the world's rice is grown by small-scale farmers in low-income and developing countries. Efficient and productive rice-based production systems are therefore essential for economic development and improved quality of life for much of the world's population (FAO, 2004c).

Rice is a highly adaptable staple with many properties that have not yet been exploited in large scale production systems. It is tolerant to desert, hot, humid, flooded, dry and cool conditions, and grows in saline, alkaline and acidic soils. At present, however, only two of the 23 rice species are cultivated. Science can help improve the productivity and efficiency of rice-based systems. Improved technologies enable farmers to grow more rice on limited land with less water, labor and pesticides, thus reducing damage to the environment. In addition, improved plant breeding, weed and pest control, water management and nutrient-use efficiency can increase productivity, reduce costs and improve the quality of the products of rice-based production systems.

New rice varieties being developed exhibit enhanced nutritional value, require less water, produce high yields in dryland conditions, minimize post-harvest losses, and have increased resistance to drought and pests and increased tolerance to floods and salinity. For example, rice varieties with salinity tolerance have been used to expedite the recovery of production in areas damaged by the 2005 Asian tsunami.

The Consultative Group on International Agricultural Research and FAO are promoting *Rice Integrated Crop Management Systems* (RICMS). By introducing integrated soil, water and nutrient management practices for sustainable rice-wheat cropping systems in Asia, RICMS would complement the introduction of new varieties and address the environmental problems that have emerged in these systems since earlier yield-enhancing technologies were introduced (International Rice Commission, 2002).

IRRI⁵³. The International Rice Research Institute (IRRI) is the world's premier research organization dedicated to reducing poverty and hunger through rice science; improving the health and welfare of rice farmers and consumers; and protecting the rice-growing environment for future generations. IRRI is an independent, nonprofit, research and educational institute, founded in 1960 by the Ford and Rockefeller foundations with support from the Philippine government. The institute, headquartered in Los Baños, Philippines.

*Science of C4 Rice. Value proposition.*⁶⁷. (2012)

Increased water use efficiency. C4 rice would need less water because water loss will be reduced and the water used more efficiently. C4 plants would have the pores in the leaves (stomata) partially closed during the hottest part of the day. Also C4 plants absorb more CO₂ per unit of water lost. C4 plants are able to do this because of the compartmentalization and concentration of CO₂ that occurs in the bundle sheath cells.

*Increased **nitrogen** use efficiency.* C4 rice would increase nitrogen-use efficiency by 30% because the plant will need lower amounts of Rubisco, an abundant enzyme that fixes CO₂ into sugars. By requiring less Rubisco for the same amount of CO₂ fixed, C4 rice can achieve the same productivity with fewer enzymes, which means less nitrogen. (enzymes and proteins contain 15% nitrogen).

Yield benefits. Models show that increased water and nitrogen use efficiency and other characteristics, would support yield increases of 30% to 50% based on comparative studies between rice and maize.

5.2.3 GMO perspectives

- Endo-gene GMO⁶⁰

One implication of the new tools is that plants can be genetically modified without the addition of foreign genes. Though it's too early to tell whether that will change the public debate over GMOs, regulatory agencies -at least in the US- indicate that crops modified without foreign genes won't have to be scrutinized as thoroughly as transgenic crops. That could greatly reduce the time and expense it takes to commercialize new varieties of genetically engineered foods. And it's possible that critics of biotechnology could draw a similar distinction, tolerating genetically modified crops so long as they are not transgenic.

Dan Voytas⁶¹, director of the genome engineering center at the University of Minnesota and one of *Talens*'s inventors, says one of his main motivations is the need to feed another two billion people by the middle of the century. In one of his most ambitious efforts, centered at the *International Rice Research Institute in Los Baños, the Philippines*, he is collaborating with a worldwide network of researchers to rewrite the physiology of rice. Rice and wheat, like other grains, have what botanists call C3 photosynthesis, rather than the more complex C4 version that corn and sugarcane have. The C4 version of photosynthesis uses water and carbon dioxide far more efficiently. If the project is successful, both rice and wheat yields could be increased in regions that are becoming hotter and drier as a result of climate change.

Only a handful of large companies can afford the risk and expense of commercializing GMO (Genetic Modified Organisms). These bio-engineered versions of some of the world's most important food crops could help fulfill initial hopes for genetically modified organisms, or GMOs. But they will also almost certainly heat up the debate over the technology. Opponents worry that inserting foreign genes into crops could make food dangerous or allergenic, though more than 15 years of experience with transgenic crops have revealed no health dangers, and neither have a series of scientific studies. The most persuasive criticism, however, may simply be that existing transgenic crops have done little to guarantee the future of the world's food supply in the face of climate change and a growing population.

- Exo-gene GMO

Developing crops that are better able to withstand climate change won't be easy. It will require to engineer complex traits involving multiple genes. Durable disease resistance typically requires a series of genetic changes and detailed knowledge of how pathogens attack the plant. Traits such as tolerance to drought and heat are even harder, since they can require basic changes to the plant's physiology.

One problem with conventional genetic engineering techniques is that they add genes unpredictably. The desired gene is inserted into the targeted cell in a petri dish using either a plant bacterium or a "gene gun" that physically shoots a tiny particle covered with the DNA. Once the molecules are in the cell, the new gene is inserted into the chromosome randomly. (The transformed cell is grown in a tissue culture to become a plantlet and eventually a plant.) It's impossible to control just where the gene gets added; sometimes it ends up in a spot where it can be expressed effectively, and some-times it doesn't. What if you could precisely target spots on the plant's chromosome and add new genes exactly where you want them, "knock out" existing ones, or modify genes by switching a few specific nucleotides? The new tools allow scientists to do just that.

One of the most promising genome engineering tools, *Talens*, was inspired by a mechanism used by a bacterium that infects plants. Plant pathologists identified the proteins that enable the bacterium to pinpoint the target plant DNA and found ways to engineer these proteins to recognize any desired sequence; then they fused these proteins with nucleases that cut DNA, creating a precise "editing" tool. A plant bacterium or gene gun is used to get the tool into the plant cell; once inside, the proteins zero in on a specific DNA sequence. The proteins deliver the nucleases to an exact spot on the chromosome, where they cleave the plant's DNA. Repair of the broken chromosome allows new genes to be inserted or other types of modifications to be made. *CRISPR*, an even newer version of the technology, uses RNA to zero in on the targeted genes.

With both *Talens* and *CRISPR*, molecular biologists can modify even a few nucleotides or insert and delete a gene exactly where they want on the chromosome, making the change far more predictable and effective.

Union of Concerned Scientists UCS⁶⁵. *Failure to yield. Evaluating the Performance of Genetically Engineered Crops*

The burgeoning human population challenges agriculture to come up with new tools to increase crop productivity. At the same time, we must not simply produce more food at the expense of clean air, water, soil, and a stable climate, which future generations will also require. In order to invest wisely in the future, we must evaluate agricultural tools to see which ones hold the most promise for increasing intrinsic and operational yields and providing other resource benefits.

It is also important to keep in mind where increased food production is most needed -in developing countries, especially in Africa, rather than in the developed world. Several recent

studies have shown that low-external-input methods such as organic can improve yield by over 100 percent in these countries, along with other benefits. Such methods have the advantage of being based largely on knowledge rather than on costly inputs, and as a result they are often more accessible to poor farmers than the more expensive technologies (which often have not helped in the past).

Although current food production is actually adequate when measured on a global scale, with issues other than agricultural yield being of greatest importance at present for determining access to food, ample production for 9 or 10 billion people poses a challenge. Producing enough food while minimizing the environmental harm caused by current industrial farming methods and supporting rural communities could well become more pressing, especially as climate change proceeds.

Consider the open question “How much does crop productivity need to increase in order to ensure adequate nutrition worldwide?” Many studies estimate that food production will need to grow 100 percent, despite projected population increases of about 50 percent; such projections are driven primarily by rising levels of global affluence, leading to increasing per capita demand for meat, milk, and eggs. Although these animal products provide high-quality protein, they also require much greater resource use and produce much more pollution and global warming emissions per unit of production compared to grains and legumes. Approximately 3,5-5,0 kg of grain are required to produce one pound of beef, 2-3 kg to produce a kg of pork, and 1-1,5 kg to produce a kg of chicken. Thus the quest for higher meat and dairy consumption in the developing world is colliding with emerging concerns about their environmental effects. High levels of meat consumption in the US are also associated with rising levels of obesity and related adverse health consequences. Therefore reduction in meat consumption, particularly in the developed countries (where such consumption is especially high), could result in substantially reducing the projected requirements for increased food production as well as in improving public health.

Finally, under the influence of the environment, food production is dynamic -climate change in particular may have substantial impacts on crop productivity by altering weather patterns. We must therefore consider how climate change may affect crop yields as it proceeds. Higher temperatures, for example, may increase yield in a few areas, but in most places yields could decline.

The failure of genetic engineering (GE) to increase intrinsic yield so far is especially important when considering food sufficiency. Substantial yield increases can be achieved through operational yield, and there is room for achieving huge operational yield increases in much of the developing world. But intrinsic yield sets a ceiling that is proving difficult to surpass.

So far, the only technology with a proven record at increasing intrinsic yield is traditional breeding, which now includes genomic methods.

Although GE may have something to contribute to intrinsic yield in the future, it would be foolish to neglect proven breeding technologies while waiting to see if such possibilities materialize. Similarly, sustainable agro-ecological methods are already showing considerable promise for contributing to operational yield, especially in the developing world, where GE has had limited impact so far.

It would be better to provide more resources for more promising technologies -traditional and marker-assisted breeding methods and agro-ecological approaches such as organic and low-external-input methods- which currently suffer from meager financial and research support. This does not mean that GE should be abandoned but rather that public resources be shifted to more propitious methods. Such a change in public policy is especially indicated for agro-ecological approaches, which, because they are knowledge-based rather than capital-intensive, are not usually attractive to large companies.

5.2.4 Agricultural yields and rapidly growing population

A surprising and troubling detail of the research is that crops and farmers don't seem to have adapted to the increased frequency of hot days. Surprising is that there has been tremendous progress in agricultural breeding -average yields have gone up more than threefold since the 1950s- but looking at sensitivity to extreme heat, no real progress seems has been made since then.

Crops with better resistance to hot climates.

Corn. During the heat wave that hit much of the United States in 2012 yields of corn were down 20%, that year was not that unusual a year compared to what the climate models predict.

Wheat is also emblematic of the struggles facing agriculture as it attempts to keep up with a growing population and a changing climate. Not only have the gains in yield begun to slow, but wheat is particularly sensitive to rising temperatures and is grown in many regions, such as Australia, that are prone to severe droughts. What's more, wheat is vulnerable to one of the world's most dreaded plant diseases : stem rust, which is threatening the fertile swath of Pakistan and northern India known as the Indo-Gangetic Plain. Conventional breeding techniques have made remarkable progress against these problems, producing varieties that are increasingly drought tolerant and disease resistant. But biotechnology offers advantages that shouldn't be ignored.

Climate change doesn't change the challenge for plant breeders, but it makes it much more urgent, says Walter Falcon, deputy director of the Center on Food Security and the Environment⁶⁸ at Stanford. Falcon was one of the foot soldiers of the Green Revolution, working in the wheat-growing regions of Pakistan and in Mexico's Yaqui Valley. But he says the remarkable increases in productivity achieved between 1970 and 1995 have largely "played out," and he worries about whether the technology-intensive farming in those

regions can be sustained. He says the Yaqui Valley remains highly productive -recent yields of seven tons of wheat per hectare “blow your mind”- but the heavy use of fertilizers and water is “pushing the limits” of current practices. Likewise, Falcon says he is worried about how climate change will affect agriculture in the Indo-Gangetic Plain, the home of nearly a billion people.

- World Fertilizer trends and outlook to 2018. FAO⁶⁹

The so-called “greenhouse fertilization effect” will produce local beneficial effects where higher levels of atmospheric CO₂ stimulate plant growth. This is expected to occur primarily in temperate zones, with yields expected to increase by 10 to 25 % for crops with a lower rate of photo-synthetic efficiency (C3 crops), and by 0 to 10 % for those with a higher rate of photosynthetic efficiency (C4 crops), assuming that CO₂ levels in the atmosphere reach *550 parts per million* (IPCC, 2007c); these effects are not likely to influence projections of world food supply, however.

The impacts of mean temperature increase will be experienced differently, depending on location.

For example, moderate warming -increases of 1 to 3°C in mean temperature- is expected

- to benefit crop and pasture yields in temperate regions,
- while in tropical and seasonally dry regions, it is likely to have negative impacts particularly for cereal crops.

Warming of more than 3°C is expected to have negative affects on production in all regions (IPCC, 2007c).

The supply of meat and other livestock products will be influenced by crop production trends, as feed crops account for roughly 25 percent of the world’s cropland.

Chapter 6. The way to action. Recommendations

The Global Picture

It is well known that agriculture and food production, at planetary scale, are quite complex matters, for they depend on geography, the soil properties and social-cultural habits. In all cases they determine the survival of human societies in vulnerable places. Hunger belongs to the history of human society, and up to now, no real systemic solution has emerged providing an optimistic perspective.

Humankind is probably facing existential challenges in the coming two to three centuries. The past century belongs probably to the fastest changes humankind has undergone. Indeed, the emergence of new knowledge and insights through major scientific and technological discoveries : in physics (relativity and quantum theory, etc); chemistry and biochemistry (polymers, genetics, etc.); space research and exploration; micro-electronics and related technological developments, and much more. Also humanistic and social sciences have evolved along similar pattern.

However, the technological evolution is accompanied with unexpected side effects, such as pollution, deterioration of the natural environment, loss of biodiversity a.o., resulting in the questioning of the final outcome of this extraordinary journey humankind has performed in such a short period of time.

The human species is -at least- facing two major challenges:

- 1st the *demographic evolution* of the human species which has been recognized since several centuries and was first described by Maltus (1766-1834);
- 2nd more recently the recognized phenomenon of *Climate Change* and the embedded Global Warming.

Both phenomena have cumulative effects in particular on agriculture production, raising the questions if the planet earth has the physical capability or *carrying capacity*, to cope with these fast evolving trends, or should the human society adapt fundamentally its behavior towards Gaïa, as described by James Lovelock.

Three basic concepts used in this research can be summarized as follows :

- The choice of the *Köppen-Geiger Climate Classification System* as an overarching approach to identify climate structures and differences on the terrestrial planet. The classification has been updated recently with satellite data in order to increase the precision of the climate zones. Five Climate Classes and some 24 Climate Zones (Czs) used in this report cover the five continents. The CZs provide an original view on the conditions for food production and its relation to demography and Climate Change.
- The *demographic evolution* in the present century and beyond (up to 2300), is a

tremendous challenge for the human species, especially but not exclusively for the food production. In total some 3-4 billion additional people have to be fed by 2100, this includes the undernourished of the present day of <1 billion people. Special attention is given to the of African continent, for the increase of the population with housing, health care, education, and much more issues, remains an herculean task.

- The use of recent *Network Sciences* and elements of the *Graph Theory*, have allowed to construct the inter-linkage of essential parameters -crops and meat production, land use and fresh water availability for agriculture output. The graphical design of the networks is done with the use of *Gephi software* and the matrix calculation through programming with *R* (both open source). The compiled agriculture data cover three crops (rice, maize, wheat), four meat types (beef, pork, sheep, poultry), land for agriculture and fresh water withdrawal, and are based on the report by the FAO Statistical Report 2013.

The combination of these three main variables provide a novel approach to a planetary food production. It is a 'physical' approach in the sense that the food has to be produced first before it can be sold or traded. Already some 5,000 data are used for graphical design and related calculations, the global picture can be further explored and fine tuned with more available data. It is widely accepted that *-one cannot solve problems in the same way they have been created-* however it is seldom translated into practice. The new sciences of Networks and Complexity have the potentiality to address this huge challenge.

Food being a daily existential need for everyone, which has never been reached for the entire human society; In fact we have to recognize a dramatic failure of the human species. The research hopes to open ways for fighting and resolving the dramatic food and nutrition situation in the present century. However it is not guaranteed that it will succeed.

The long term scale is an enormous obstacle for action in this complex phenomenon. The impact of global warming on agriculture production will probably take decades to understand clearly what has to be undertaken; the demographic increase has been a dynamic process over millenniums and still a long term projection appears to be extremely difficult if not impossible. The impact of Climate Change on the human condition and the remediation of the impact will take most likely centuries. The very long time has always been matter to handle, however no individual or community can escape the effects of climate variations, and everybody has to eat for survival and perpetuation the community the individual belongs to. However history has clearly shown the degree of difficulty to establish a log term.

The vision here expressed is that the new scientific approaches and insights will be helpful of overarching local interests and situations and stimulate global decisions and actions. We address the present findings to all individuals on earth, and in particular to leaders of civil society, political leadership of local, regional, national and international bodies. To all concerned about the our society and its future, we are living an exceptional period in human history and facing exceptional challenges as well.

Proposals for handling the planetary food 'problématique'

The very first challenge at the horizon 2100 is to provide enough food for everyone of the then ~10 billion living people on earth.

The call for a *global governance body for agriculture production* has to be envisioned seriously, for food scarcity is a daily and existential matter, and thus extremely vulnerable for getting or maintaining social stability. Such a governance body can be thought of within existing world institutions or created out of immediate urgency, worldwide. The need for large scale investment over several decades would belong to the mission of such a governance body.

In fact the question is again, if the world governance and large scale investment are not envisioned, what are the consequences? The phenomenon of Climate Change interact with physical equilibrium of the planet's biosphere and thus intervenes in the agricultural sphere. So indirectly the survival of the human species is at stake, calling for a sustaining and overarching approach.

1st Priority. *Allocating the highest priority to planetary agriculture, and its priority cannot be disconnected from planetary Climate Change remediation.*

A specific governance body for agriculture investment and production must be envisioned, in order to avoid massive social unrest and political instability in several regions on earth and over several decades to come.

Water-withdrawal for Agriculture. Agriculture is by far the largest user of fresh water, 75% of the total water-withdrawal is used for agriculture production. Today already, in several parts of the earth, water scarcity is a threat. Water scarcity is essentially a regional matter, consequently the measures to be taken belong to the concerned communities.

Climate variability and extreme weather phenomena increase the difficulty of the management task seriously, however there seems not be any alternative. It has been stated that water management needs to become the highest priority for sustaining and expanding agricultural output.

⇒ **2nd** *Management of fresh water resources has to become the highest priority within the food production.*

Land for Agriculture. The use of of the land areal for meadows and pastures compared to land for crops is many times higher and varies from 5-20 depending on the geographical area.

⇒ **3rd** *It is proposed that some of today's meadows land is converted to land for crops.*

Obviously the conversion should be practiced in areas which are potential suitable for crops production. The risk is also that biodiversity will decrease in these converted areas, and that

social and cultural implications will arise as well, to for example pastoralists habits and cultures. The conversion will take time to get these soils adapted for crops production, however, one should remind that the soils used today have been adapted for crops production through human labor and intervention.

Crops and Livestock production

Crops production.

Breeding. Several The most appealing technique has been practiced for centuries and has gained high attention over last 75 years and developed on a systematic basis by Norman Borlaug. Fascinating results have been obtained for wheat, direct yield improvement as well as indirect increase efficiency through plant height, resulting in wind resistance and higher harvest yield, higher resistance to pests also improving the efficiency of output.

The new plants have shown to be beneficiary in different countries and continents (Mexico and India). Breeding techniques continues to be pursued.

⇒ **4th *Breeding remains an exceptional process for enhancing food production.***

GMO. Genetic Modified Organisms have been applied for several decades. Two types of genetic modification are in use : endogenous and extro-genous genetic plant intervention.

– *endo-genous* genetic modification consists in modifying internal plant processes without involving external input. These techniques seem to be very promising, then they get resistant to pests. Moreover endo-genic modifications are comparable to breeding, increasing direct plant production. With the help of adapted technological knowledge these traits are in principle faster to be obtained compared to field breeding.

– *extro-genous* genetic modification consists of introducing genes of external organism : e.g. gene from *Bacillus Thuringiensis*, resulting in BT corn traits resistant to insects and pest of maize. These techniques do not improve direct plant yield, but protects against damage and loss of invasive pests.

⇒ **5th *Plant breeding and endo-genous genetic modification bear the necessary efficiency of plant production improvements.***

Photosynthesis. The *C4 rice traits* show a higher GHG uptake then the C3 rice variant, and also more resistant to less water availability and global warming in general.

⇒ **6th *Extension of higher GHG uptake and resistance to drought through specific improvements of photosynthesis.***

Livestock and meat production. The increasing demand for meat becomes a large scale problem. The energetic balance for meat output is very poor, especially for beef. The socio-economic evolution enhances the consumption of meat in many countries with fast economic growth. The consequences are numerous, more water-withdrawal, crops production for feed, additional land use. The husbandry practices of pigs and poultry are already introduced in the beef and dairy production, resulting in decreased meadows use, however,

the land use and water-withdrawal for feed production remains the same.

⇒ **7th Industrialization of animal husbandry, in particular for beef, is advantageous, for it requires less land use allowing increased crop production, however it alienates humans from the biosphere further.**

- Continents.

African continent. Among the different continents analyzed, the African continent appears to be most challenged in this century. Its geography with the Sahara desert and the Sahel, representing some >30% of the total surface of the continent and the increasing desertification due to global warming, are cumulative difficulties for developing its populations. The demographic increase by a factor ~2.5 or more is an enormous burden to overcome as well. Already food scarcity (expressed per capita) is problematic.

A massive investment in agriculture -during several decades- is an absolute must, the focus should be on a *small scale mechanization* of local farmers as well increased *capacity building* particularly centered on agriculture. Capacity building has already been stressed in previous reports, however in the analysis on agriculture, the impact on the populations requires the highest priority.

⇒ **8th Massive investment in agriculture is a must for Africa, allowing small scale mechanization for local food production. Capacity building belongs to the investment process.**

- Global management

Food for everyone is a *humanistic objective*, however by far not reached yet and the balance projected to the end of the 21st century is not quite optimistic. The major reason lies in the planetary demographic expansion of some three billion individuals, plus the still undernourished of about one billion people. The expected increase of meat consumption -expressed in human equivalents- has to be added to the total amount of food production and rises once more the total number of additional humans (equivalent) to be fed to some, resulting in some five billion people. The Climate Change through *global warming* and *extreme weather* conditions, enhance the need for an overarching approach or governance system or institution.

This has happened already in the past on smaller scales, however on large scale, hunger can/will trigger, disturbances on such favorable breeding grounds.

⇒ **9th Humankind has to face reality, systematic shortage of food, on a planetary scale, will lead to social unrest and consequently to political instability, in several parts of the planet.**

Biofuels. The concept and the practice of producing *biofuels* from food and feed is entirely unsustainable, not only it diminishes the quantity of produced food designated for humans, but, it takes away arable land and water, very much needed for human consumption.

⇒ **10th Producing biofuels from food and feed is entirely unsustainable and must be interrupted immediately.■**

Abbreviations, Acronyms & Institutions

FAO	Food and Agriculture Organization, United Nations
UNFCCC	United Nations Framework Convention Climate Change
IPCC	Intergovernmental Panel on Climate Change
SRES	IPCC Special Report on Emission Scenarios 2000
RCPs	Representative Concentration Pathways
RCP8.5	GHG concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) Describing possible climate future depending on how much GHG are emitted.
NOAA	National Oceanic and Atmospheric Administration
GHCN	The Global Historical Climatology Network of NOAA
IWMI	International Water Management Institute
GPCC	Global Precipitation Climatology Centre at the German Weather Service
GHCN	Global Historical Climatology Network
GCM	Global Climate Model
NCDC	National Climatic Data Center, FAO
CRU	Climate Research Unit of the University of East Anglia
CRU TS2.1	Dataset from Climate Research Unit
TYNDALL	Tyndall Centre for Climate Change Research
TYN SC 2.03	Dataset from Tyndall Centre for Climate Change Research
RICMS	Rice Integrated Crop Management Systems International Rice Research Institute in Los Baños, the Philippines
Hadley Centre	Hadley Centre for Climate Prediction and Research
HadCM3	Hadley Centre Coupled Model, version 3. A coupled atmosphere-ocean general circulation model (AOGCM)
PCM	Parallel Climate Model
GHCN2	data base containing historical temperature, precipitation, and pressure data for thousands of land stations worldwide.
CM	Climate Model
IAM	Integrated Assessment Model
IAV	Impacts, Adaptation and Vulnerabilities
CMIP5	Coupled Model Intercomparison Project
MIROC	Model for Interdisciplinary Research on Climate
IRRI	International Rice Research Institute
CIMMYT	International Maize and Wheat Improvement Center
WB	World Bank
CRISPR	genetic modification tool, altering the germline of humans, animals and other organisms, and manipulating the genes of food crops.
TALENS	a widely applicable technology for targeted genome editing

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Afterword

The authors present these findings to all individuals on earth, in particular to leaders of civil society, political leadership of local, regional, national and international institutions. All persons have the right to have enough daily food for themselves and their families. To all people concerned about the future of our society.

&

Top-Priority

Allocating the highest priority to planetary agriculture of all agendas. This priority cannot be disconnected from planetary Climate Change remediation.

A specific governance body for agriculture investment and production should be envisioned, in order to avoid massive social unrest, violence and political instability over longer periods and in several regions on earth, due to the absence of food and fresh water.