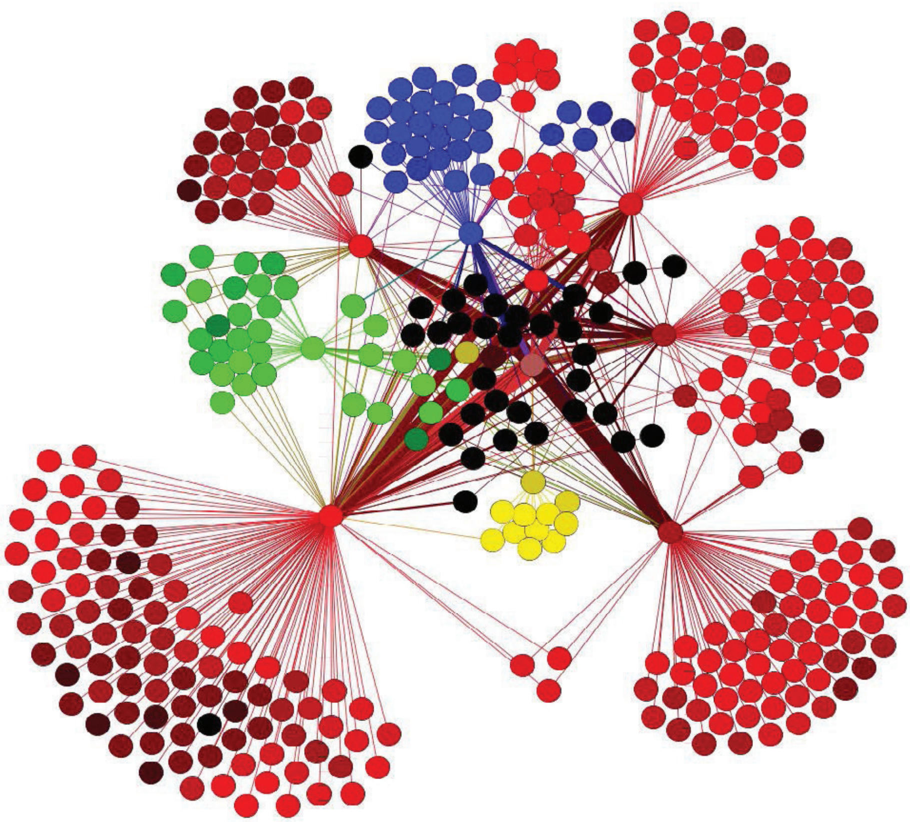
Raoul A. Weiler Kris Demuynck

Food Scarcity Unavoidable by 2100?

Impact of Demography & Climate Change



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Raoul A. Weiler
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Weiler R.(2005), *The Kyoto Protocol and its Socio-Ethical Aspects.* in Vermeersch E. et al (Ed.), *Reading the Kyoto Protocol. Ethical Aspects of the Convention of Climate Change.* Eburon

This work is dedicated to our children,
grandchildren and to all the
children of the World

who already live and will live in the
21st century and will face the
enormous challenges
humankind has to overcome

****

Also, in memory of Professor Norman Borlaug

for his trend setting plant breeding research

Nobel Price for Peace 1970

Comments and Appreciations

Food for every human on the planet Earth-2100. The approach of Science of Net-work 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'*.

Professor Dr. Timi Ecimovic

****

This innovative use of the Science of Networks to the future of in a changing climate illustrates the power of new methods of analysis to illuminate the tight linkage between all the challenges we face. It shows how vital it is to fully integrate the agricultural and land-use activities into efforts to limit climate change. It shows that policies for and land-use must be changed if we are to feed a growing world population and reduce carbon emissions.

Dr. Peter Johnston
Member of the Club of Rome
Senior Adviser for the European Policy Center

****

This book can be viewed as a publication succeeding the first Report to the Club of Rome *The Limits to Growth*. In contrast, however, the authors do not limit themselves to the description and evaluation of threatening developments. The work is rather focused on solutions, its main focus is placed on the nexus between climate change and demography, agricultural production, land-use changes and fresh water availability, and the avoidance of hunger and societal instabilities. To find proper solutions to this complex issue the ***New Science of Networks*** is used as a novel method of analysis, a very promising tool for decision makers at large.

Peter A. Wilderer
2003 Stockholm Water Prize laureate
Professor emeritus of excellence, TU Munich
Founder of EASA´s Institute for Earth System Preservation.

****

This book comes at the right time. In the past, we have not too much focused on. Now is becoming a very important and viable issue. In one way, it is an indicator of our climate changes and how we can provide enough food for our growing population. Agricul-ture also depends to the land availability. The industrial for food production with use of fertilizers and pesticides gives new environ-mental challenges. Water becomes the next problem too. Of course, it is a very complex issue, which can be approached by a new science network as a global effort, as a basis for future decisions and development.

Felix Unger
Founder and President of the European Academy Sciences & Arts.
University of Salzburg

****

This book seeks to describe and explain these remarkable interact-ions with the help of network technologies, also making them easier to understand and discuss on an ultra-complex global scale. It is a new approach to achieving the necessary transparency for addressing the risks and opportunities presented by a global of the future.

Professor Dr.-Ing. Martin Grambow
Head, Director General for Water and Soil Protection, Bavarian State
Ministry of the Environment & Consumer Protection.
Technische Universität, Muenchen, Germany.

****

The strength of this report lies in the excellence of its process in the quantification of a wide range of interdependent factors crucial to the sustainability of agriculture and food production. This report provides scientific innovation with social responsibility and produ-ces an extraordinary level of clarity concerning the threat to huma-nity posed bay unrestrained climate change and the possibility of food scarcity. This is a profoundly good study and is worthy of the widest distribution in public policy circles as well as public opinion fora.

Heitor Gurgulino de Souza & Winston Nagan
President & Chairman of the Board of Trustees
World Academy of Art and Science

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Abbreviations, Acronyms & Institutions

FAO	Food and 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 AR5 describing possible climate future depending on emitted GHG amounts
NOAA	National Oceanic and Atmospheric Administration
GHCN	The Global Historical Climatology Network of NOAA
IWMI	International Water Management Institute
GPCC	Global Precipitation Climatology Center 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	Data-set from Climate Research Unit
TYNDALL	Tyndall Center for Climate Change Research
TYN SC 2.03	Data-set from Tyndall Center for Climate Change Research
LAMS.	Laboratoire d'analyse de sol.
RICMS	Rice Integrated Crop Management Systems International Rice Research Institute in Los Baños, the Philippines
Hadley Center	Hadley Center for Climate Prediction and Research
HadCM3	Hadley Center 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	**g**enetic modification tool, altering the germline of humans, animals and other organisms, and manipulating the genes of food crops.
TALENS	widely applicable technology for targeted genome editing

Executive Summary

Agriculture has emerged with the appearance 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 sustainability 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 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'.*
The research project makes 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 of countries. This approach is distinct from usually defined borders based on juristic defined and recognized identities, applied by international organizations. The linkage between countries and continents with the Climate Zones as defined by the Köppen-Geiger system, does exist and allows the combination of Climate Zones with countries. Used data are provided by United Nations institutions, UN-FAO and UN-ECOSOC.*

*The **demographic increase** of the 21st century, requires to look in a different way to the significance 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 investigating a real existential matter for the human species. Additionally the phenomenon of Climate Change increased the curiosity to look for their application. The present approach deliberately is limited to 'physical' parameters in an analogous way of the famous report to The Club of Rome, The limits to growth (1972). No economic data nor trade aspects have been addressed.*

*'Open source' software has been used such as: **Gephi** (The Open Graph Viz Platform) and the program language, **R,** for statistical analyses. 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 matrix, dendrograms, decision trees and the Kamada-Kawei algorithm. All help to look for correlations among Climate Zones and the agricultural parameters: crops, meat, arable land and fresh water use.*

In the final chapter a focus on the ethical aspects of food for all are addressed as well as 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 at present fluctuates from 8 to 52 depending on the continents.*
- *Improve the management of Water-withdrawal globally and in particular for agriculture, which uses already 75% of the total withdrawal. The effects of climate variability, global warming, extreme weather conditions and increased demography have to be added to the today's people living with dramatic water scarcity.*
- *Increase crops production through generalized breeding, applying endogenous GMO techniques, in-creasing C4 plants which absorb higher quantities of carbon dioxide and showing better adaptability to changing weather conditions (drought) and/or environmental ones (salinity).*
- *The use of food and feed resources for producing Bio-fuel is considered unsustainable and therefore not recom-mended. 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 in-crease 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 in-creasing 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 acquaint 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 ethical dimension of this exceptional world situation is addressed, in which the responsibility of all leaders of society will be required to overcome traditional and cultural as well political and philosophical differences, among societies. Humankind faces a unique period of history in which ethical values have to go hand in hand with techno-scientific know-ledge, for the benefit of its own existence.*

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

Preface

Agriculture and food production, at planetary scale, face tremendous challenges in the present century. Enough food for all individuals on earth has never been reached, and still today ~1 billion persons are underfed or die from hunger.
The present research has the objective to enlighten the situation of the present century for production as well as the necessary basic resources for agricultural production : crops, meat, arable land and fresh water. The food part is composed of: three crops -rice, wheat and maize- and four meat -beef, pork, sheep/goats and poultry.

The new basic variables used in the analysis are :

- The Climate Classification System of Köppen-Geiger (KG). This system has been developed more than a century ago, but as been regularly actualized and updated with data from satellite observations. The Köppen-Geiger system allows to look at geographical regions independent of national borders. The classification is based on temperature and precipitation data and each climate zone (CZ) is defined with threshold values for temperature and precipitation. Each CZ is identified by three letters of which the first one corresponds with five climate classes, described as follows: *A* tropical climate; *B* dry climate; *C* mild temperate; *D* snow climate; *E* polar climate. In total 25 CZs are used in this publication, the other letters describe specific CZs in each class.
- The demographic data are taken from UN Department Economic and Social Affairs and cover the period of 1950 to 2300.

Additionally these data are complied per continent which will appears extremely useful for analyzing the food problematic at that level, especially projected to the 2100 horizon.
- The new Sciences of Networks are applied, in particular its graphical approach, with the use of the 'open source' software of ***Gephi*, **as well as the programming language ***R*** for statistical analyses, resulting in different diagrams such as *adjacency matrix, dendrograms, decision trees* and the graphical output with the *algorithm of Kamada-Kawai*. These graphical presentations illustrate the correlations as clusters CZs for a given food substance e.g. meat.
- The effects of Global warming on agricultural output are descriptive and taken from a variety of publications. A wide use of IPCC assessment reports have been applied for better understanding of the evolution of Climate Change and related to demography. In particular attention has been given to the African continent, which faces a dramatic demographic increase by a factor 2.83 over the present century and a frightening increase of desertification. Agricultural output depends on the availability of specific resources such as : mineral fertilizers, in particular of phosphor which is available in limited quantities; fresh water made available in principle through desalination; the conservation or restoration of soil quality, which is threatened through the overuse of chemicals leading to the destruction of biological life and the death of soils leading to unproductive food production. The dynamics of Global warming, up to the 2100 horizon, remains extremely difficult to evaluate, mainly due to lack of appropriate data. A realistic diagnosis is therefore very speculative. It requires further acquisition of new and additional data and knowledge as well.

Agriculture is clearly a very complex matter which needs new approaches with the objective to obtain holistic insights and overarching knowledge for sustainable solutions for centuries to come. Indeed, Climate Change and its remediation is a matter of centuries rather than of decades.

The ethical dimension has been addressed as well, and appeals for an overarching understanding and necessity of the food availability for all humans. An increased responsibility of all leaders in society is therefore a prerequisite for success.
The final chapter lists nine recommendations to apply and represent specific action domains for improving the food availability. In fact they are nothing less, sustainability issues to be applied right now but certainly in the current of the present century.
The main suggested recommendation concerns the creation of an international body dealing with the food problematic. It is recommended at planetary level, for the entire human species is concerned. It is stressed anew that if food scarcity at large scale will create major social unrest of large populations accompanied with violence, political instability in many places on earth and civilization crises will be unavoidable.

Therefore, optimism is not enough to solve the future food availability.

Chapter 1. Introduction

The emergence of new sciences such as the New Sciences of Networks and Complexity, are likely able to provide new approaches to the challenge of world wide agricultural production. 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 way, 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 worldwide. 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!
The *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 , that importing food from other places of the earth for the consumption elsewhere, means the creation of a footprint on the place of production.

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 the 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 most likely is higher in reality. An additional quantity of new born humans -of some 2.5 billion individuals- will be added to the undernourished by the end of the

21st century. This means that about half of today's human-kind has 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 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. Albeit, human species could create its own collapse[9].
Will humanity, with its actual world governance structures, succeed in answering this real vital question? This is not yet known. However, if humankind does not succeed, then obviously major social conflicts will emerge and worldwide.

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 (KG) Climate Classification System*[10] 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 KGCCS system has its roots in the early 20th century, it has been updated with satellite observations, making it a modern tool, with a resolution of 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, in this research, along the following structure, Climate Zones (CZs) → Continents → Countries. The use of FAO data, based on countries, have been linked to CZs allowing the cross reference between the different parameters.

The demographic evolution of the present century is 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.

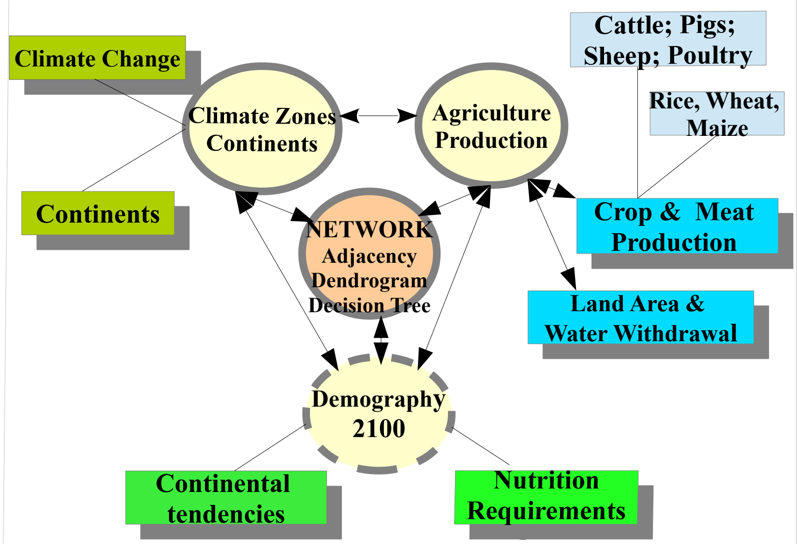
The fundamental question to be answered is the impact of Climate Change on food production[12] and above all to the increased demand of food by 2100. Temperature and precipitation are accepted to be the main drivers of climate change and global warming. However, there are other parameters such as weather 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 not yet integrated in this approach of investigation.

Our recognition also goes 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 2. The Structure of the Project

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 triangles **Agricultural Production** and **Climate Zones** are interrelated and connected to **Demographic Evolution**. Large attention is given to **Continents** in order to highlight important differences, in particular, concerning the evolution of their demography. In the center of the diagram is the applied methodology of the **Science of Networks** for correlating their mutual interactions. The time scale is projected to cover the present century.

Fig 1 Schematic Overview Project



Scarcity of food has occurred all over the history of humankind due to a manifold of events, and it is still a fact at the present day.

According to UN-FAO Statistics[8] for the years 2011-2013 there are still 842 million people suffering malnutrition and/or hunger, representing about 12% of the entire population.
The application of the *Sciences of Networks*[13] have the potentiality of another approach, not applied before, to shed a better light on the global conditions of food production. 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, due to lacking of necessary data as well as to unpredictable major events. This would lead to totally wrong evaluations of human condition.

2.1 Applying Sciences of Networks and Complexity[14,15,16]

Graph theory[17] 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[18,19] are at the front line of new knowledge acquisition. They focus at 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.

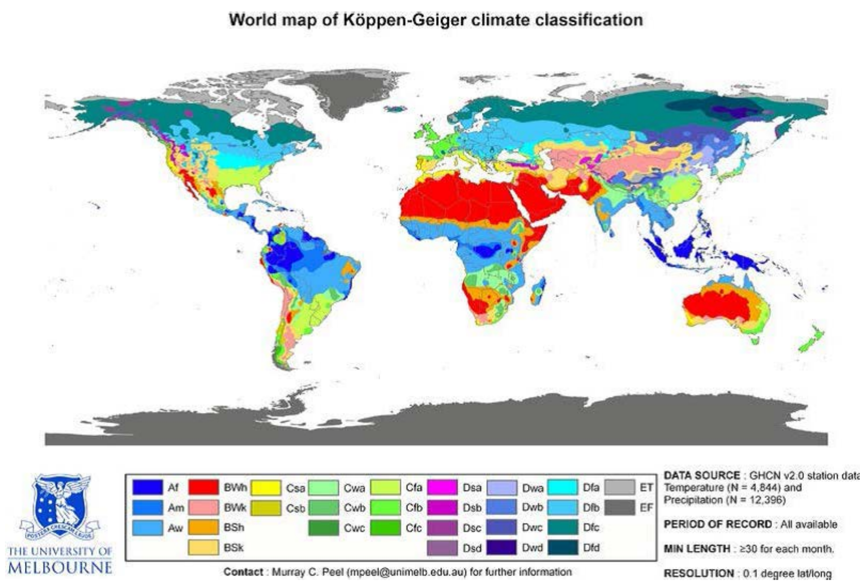
Some recent insights, in a large variety of domains, demonstrate the richness of the applicability of these sciences e.g. the structure of the Internet, the metabolism in bacterial cells, social networks, etc. Other domains of application can be envisioned -or are in the mean time explored- to bring 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; decrease 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: impact on food production by Demography and the of Climate Change.

2.2 The Köppen-Geiger Climate Classification System

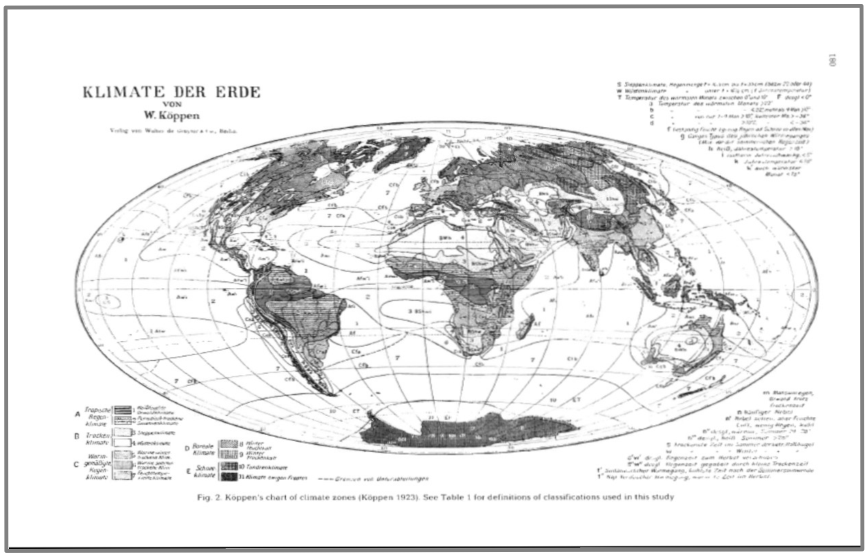
The *Wladimir Köppen* climate classification is a widely used system. It was first published by Wl. Köppen in 1884, with several later modifications by himself, notably in 1918 and 1936. Later, the climatologist *Rudolf Geiger* collaborated with *W. Köppen* on changes to the classification system, which is now referred to as the **Köppen-Geiger Climate Classification System (KGCCS).**

Fig 2a Illustration of the Climate Zones



Many researchers routinely use it for their own particular research purposes. *Peel et al*[20,21] have used for a global analysis of precipitation phenomena. *Lohmann et al*[22] (1993) have applied the KG 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 map.
A comprehensive Köppen world map drawn from gridded data to date is that of *Kottek et al*[23] (2006) who presented a map with 31 climate types at a resolution of 0.5° latitude by 0.5° longitude based data sets for the period 1951–2000, from both the CRU (Climate Research Unit, the University of East Anglia, UK), and GPCC (Global Precipitation Climatology Center, Deutscher Wetterdienst, Offenbach am Main, D.)

Fig 2b The hand-drawn map of the year 1923



The choice of climate zones, rather than countries with legal boundaries, as an overarching system allowing the correlation or linkage of physical and geographical properties has been found appropriate for estimating the impact of climate change and the demographic evolution. 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, the choice went to climate zones.

A fair picture of the terrestrial climate zones is illustrated in Fig 2a, the map of the actual status of the Climate Zone classification and in Fig 2b the hand-drawn map of the year 1923 is included in this paper for its beauty of an old picture[22].

- Description of the Climate Zones

The Köppen-Geiger climate classification system consists of five major classes and a number of sub-types under each major class, as listed in Table1. All the major classes, are based on the combined criteria relating to monthly, seasonal or annual average temperature and precipitation.

Therefore, the classification scheme as a whole represents different climate regimes of various temperature and precipitation combinations.

- The ***tropical climate A*** is characterized by the lowest mean monthly air temperature being equal to or higher than 18°C, while the four sub-types are decided based on the annual and seasonal mean precipitation.
- The ***dry climate B*** is determined by the annual mean precipitation and temperature, as well as the annual cycle of precipitation. Different sub-types distinguish between arid (desert) and semi-arid areas and further seasonal difference in precipitation conditions.
- The ***mild temperate C*** represents the climate with the lowest monthly mean temperature between −3°C and +18°C, while the different seasonal precipitations give rise to the four sub-types.
- 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°C, and the two sub-types further divide the major group into two temperature conditions.

According to *Chen W. Hans* and *Deliang Chen*[24,25]. The KG Climate Classification System comprises a total of 31 climate zones (CZ) described by a code of *three letters*.

A description of the symbols and the criteria used to define the KG-Geiger climate types is provided in Table 1.

- First and Second letter

Table 1a Structure of Köppen-Geiger Climate Zones

Class	CZ	Class Description	Detail Description, Scond letter
A		**Tropical/mega-thermal clima.**	
	Af		Tropical rain forest
	Am		Tropical monsoon
	As		Tropical Savannah with dry summer
	Aw		Tropical Savannah with dry winter
B		**Dry-arid & semi-arid- clima.**	
	Bw		Desert (arid)
	Bs		Steppe (semi-arid)
C		**Temperate/meso-thermal**	
	Cs		Mild temperate with dry summer
	Cw		Mild temperate with dry winter
	Cf		Mild temperate, fully humid
D		**Continent./micro-thermal**	
	Ds		Snow with dry summer
	Dw		Snow with dry winter
	Df		Snow, fully humid
E		**Polar & Alpine climate**	
	ET		Tundra
	EF		Frost

- The Third letter

All precipitation variables are in units of millimeters (mm) and all temperature variables are in units of degrees Celsius (°C).
- The *Temperature parameter.*
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 °C has to occur for at least four months *M. Kottek et al*[23].

Table 1b Temperature

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

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.

- 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 °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:

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

Application of CZ in this analysis

In the present study only 25 zones have been retained, the ones not considered are : As (interchanged with Aw); Csc, Cwc, Dsb, Dsd and Dwa; they occur only in very small areas[20] and are added to the closest larger one.

- 3 *A tropical* (Af, Am and Aw), {As};
- 4 *B arid* (Bwh,Bwk,Bsh and Bsk);
- 7 *C temperate* (Cfa,Cfb,Cfc,Csa,Csb,Cwa,Cwb), {Csc, Cwc};

- 9 *D cold* (Dfa,Dfb,Dfc,Dfd,Dsa,Dsc, Dwb,Dwc and Dwd), {Dsb, Dsd, Dwa};
- 2 *E polar* (ET and EF).

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

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 Peninsula 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%)*. [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].

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,

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%)*.

Table 2 Summary Continents & Climate Classes

Continent	***A* in %** [Tropical]	***B* in %** [Dry]	***C* in %** [Temperate]	***D* in %** [Contin.]	***E* in %** [Polar]
Africa	31.0	57.2	11.8	0.0	0.0
Asia	16.3	23.9	12.3	43.8	3.8
Europe	0.0	36.3	17.0	44.4	2.3
Northern A.	5.9	15.3	13.4	54.5	11.0
South A..	60.1	15.0	24.1	0.0	0.8
Australia	8.3	77.8	13.9	0.0	0.0
Planet	**19.0**	**30.2**	**13.4**	**24.6**	**12.8**

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).

When Climate Zones are linked per country and have more than one zone, this distribution is expressed in percentage of surface, which is than further used for the other parameters (crops, meat, land for agriculture, fresh Water- withdrawal). The basic structure of the project is given in the following order: Climate Classes (5), Climate Zones (25), Continents (5), Countries (150).

2.3 UN-Demography Data

Humankind shows since several decades a strong increase -hyperbolic- of its demography[26], 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 demographic[27] 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, Asian and European continents for the period from 1950 to 2300. 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 rather 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.
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 disruptions take place 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 and environmental instabilities a.o.

- Populations of Continents
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 looking into the future.

Table 3a Demographic extension for different periods and continents

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

In Table 3b the data are presented in terms of ratios over the given time periods. The demographic evolution from 1950 to 2100 is simply overwhelming: in some five generations the world population as grown from 2.5 to 9.1 billion people or by a factor ~3.6; this century by a factor ~1.5.

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

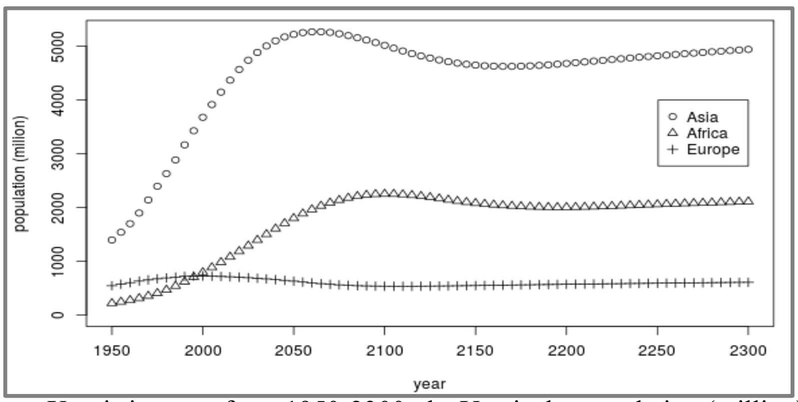
	Ratio 1950-2100	Ratio 2000-2100	Ratio 2015-2100
Africa	10.19	2.83	2.08
Asia	3.59	1.36	1.15
Europe	0.98	0.74	0.75
LatAm &Carib.	4.38	1.41	1.17
Northern Am	2.76	1.50	1.30
Oceania	3.60	1.49	1.26
World	***3.60***	***1.49***	***1.26***

The **African continent** shows a 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 by a factor of about 1.36 to 1.50, which corresponds with the average increase of the world population.

Fig 3. The demographic evolution of three continents



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

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 *capacity building*[28] and education at all levels, to provide health-care and hospitals, to build shelters and decent housing, to build and extend infra-structure for communication, etc. This is far from evident. For the entire planet the challenge of 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	1.22
E	Polar & alpine	0.058
Sum	Planet	6.928

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 with 0.058 billion people almost negligible. 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 3. Agricultural Production. Data Compilation

The impressive amount of data available from the FAO Statistical Department[29,30] facilitated substantially the analysis of the present planetary situation of food production.
The here 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.
Besides the choice of KG 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 (per capita), which again leads to interesting conclusions as well.

3.1 Crops & Meat Production

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.

3.1.1 Data per Continent

The data for the different continents as well as for resources will be extensively listed in Volume II.

Afri. Africa has been kept unchanged;
Asia. Asia minus those added to EUR;
EUR. The Russian Federation, Ukraine, Belarus and Georgia are added to EUR (instead of Asia);
NAM. Northern America includes North & 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 ~< 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 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 than further used for the other parameters (crops, meat, land, fresh water availability, etc.).

- Synthesis. Crops & Meat output per Continent (5a) & Climate Class (5b)

For clarity, a synthesis of the manifold of data -about 5,000- for crops and meat have been put together per continent Table 5a, and per Climate Class in Table 5b.

***Table 5a Synthesis Crops & Meat Output* per Continent**

Continents	Population	Crops			Meat			
		Rice	Wheat	Maize	Beef	Pigs	Sheep+goat	Poultry
	mio	10^3tons	10^3 tons	10^3 tons	10^3 tons	10^3 tons	10^3 tons	10^3 tons
	2010	2010	2010	2010	2010	2010	2010	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***

Large differences among the continents do exist, depending on their geographic situation e.g. rice production and cultural customs, pigs output.

***Table5b Synthesis Crops & Meat Output* per Climate Class**

Climate Class	Population mio 2010	Crops Rice 10^3tons 2010	Wheat 10^3 tons 2010	Maize 10^3 tons 2010	Meat 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*

3.1.2 Data per capita

The same data of the above tables but related to the population number (expressed in: per capita) are compiled in the Tables 6a & 6b. A much better picture emerges from this calculation and stresses again the big differences that exist among the continents and their food provision today.

Table 6a Synthesis. Crops & Meat per Continent per capita

Continents	Population mio 2010	Crops Rice kg/ca/y 2010	Wheat kg/ca/y 2010	Maize kg/ca/y 2010	Meat 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 *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 & 3b), a serious -if not dramatic- challenge to face. 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.

In Table 6b the same data are correlated to Climate Classes; *A* (Tropical), *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 6b Synthesis. Crops & Meat per Climate Class per capita

		Crops			Meat			
Climate Class	Population mio 2010	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*

3.2 Land Area and Water-withdrawal in Agriculture

In a similar way as with crops and meat, the analysis is extended to available land 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. Available land for crops and animal husbandry, including *pasture,* are increasingly a source of

concern: uncontrolled expansion of urbanization for infra-structure (roads, cities and suburbs, etc.). Increasing migration of people from farms towards urban areas resulting in a population density of about >70% in cities by the end of the century. Additionally, a further reduction of output is related to: extreme weather conditions due to intense rainfalls and storms, increased desertification of entire regions, all contribute in lowering arable surface.
Increasing the overall efficiency of crops and meat output, reducing the loss of nutrients in the logistic chain from the harvest to the dishes, are insufficient for answering the rising need for food. The available land for agriculture is a question to be addressed very seriously, in particular its biological condition. The wrong use of chemicals, as indicated by LAMS laboratory[31], in the form of biocides results in the destruction of the soil structure and therefore in the efficiency of the agricultural output.
Forests. If additional land will be made available through the elimination of *forests*, as is already practiced for some decades in some continents, the equilibrium of atmosphere-biosphere will be modified and probably in irreversible ways, resulting in additional impact on global warming. Indeed, forests play a significant role in the *thermodynamic* and *hydro-dynamic* conditions of the planet: dynamic interaction of the atmosphere with the forests surface; rainfall, humidity and average temperature. They play an essential role in maintaining the *terrestrial bio-diversity,* but also to the 'physical' condition of the planet and the process of the climate stability.
Fresh water situation. Unfortunately in several regions of the terrestrial planet the surface and phreatic 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 due to rising temperatures, 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. Many 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 land for meadows and pastoral for their use for crops production.

3.2.1 Data Land use and Water-withdrawal

The compilation of the data of Land for agriculture and Water-withdrawal of continents and countries is based on the same FAO[29] S*tatistical Yearbook 2013*. The Tables 7a and 7b show the synthesis of the different data for land use and Water-withdrawal per continent and per Climate Class.

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 the surfaces for crops production, although it must be recognized that not all land used for meadows & pastures can be transformed to land for crops

Table 7a Synthesis Land & Water-withdrawal per Continent

				Agriculture Area			*Water Withdrawal*	
Continent	**Population**	**Total Land**	**Total Agri**	**Arable Area**	**Crops**	**Meadows Pastures**	**Total**	**Agricul.**
	Thous. #	**Tkm² 2009**	**Tkm² 2009**	**Tkm² 2009**	**Tkm² 2009**	**Tkm² 2009**	**mio m³/y ~2000**	**mio m³/y ~2000**
Afria	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***

production, due to geographical situations. For those parts of land which could be adapted to crops production additional investments over longer time frames -a few decades- will be required to obtain acceptable efficiency.

***Table 7b Synthesis Land & Water-withdrawal* per Climate Class**

				Agriculture area			*Water Withdrawal*	
Climate Zones	Population # Thous.	Total Land Tkm² 2009	Total Agric. Tkm² 2009	Arable Area Tkm² 2009	Crops Tkm² 2009	Meadows Pastures Tkm² 2009	Total mio m³/y ~2000	Agricul. mio m³/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*

With increasing population and the rising of the average living standards, the demand for meat will enhance the demand of vegetation for fodder, as well as meadows/ pastures[32] surfaces 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 techno-logical evolution may not be applicable or appreciated for now in every country, however the provision of enough food for everybody could require such 'quantum jump'. 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.
Continents. The ratio of the amount of *land for agriculture* to the *total* amount of available land is for the continents (Table 7a): Africa ~39%; Asia ~54%; Europe ~21%; NAM ~28%; and SAM ~40%; globally 39%.
Climate Classes. The ratio of land for *crops* compared land for *meadows & pastures* is for the Climate Classes (Table 7b) : *A* ~13.1%; *B* ~1.9%; *C* ~4.4%; *D* ~3.5% and *E* ~10.0%; globally the ratio is ~4.4%.

3.2.2 Data per capita. Land use and Water-withdrawal

For comparison the individual fresh water use is estimated to be 150 to 400 liters water per day per person (52.5 to 140 $m^3/y/ca$) in industrialized societies. The use per capita for individual and domestic use is much **l**ower than for agriculture output.

***Table 8a Synthesis : Land use & Water-withdrawal* per Continent & per Capita**

				Agriculture Area			*Water-withdrawal*	
Continent	**Population**	**Total Land**	**Total Agri**	**Arable Area**	**Crops**	**Meadows Pastures**	**Total**	**Agricul.**
	Thous. #	**$10^{-3}km^2/ca$ 2009**	**$10^{-3}km^2/ca$ 2009**	**$10^{-3}km^2/ca$ 2009**	**$10^{-3}km^2/ca$ 2009**	**$10^{-3}km^2/ca$ 2009**	**$m^3/y/ca$ ~2000**	**$m^3/y/ca$ ~2000**
Afria	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***

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.

Continent per capita (Table 8a). The ratio of the amount of Water-withdrawal for agriculture to the total amount of Water-withdrawal is: Africa ~83%; Asia ~77%; Europe ~28%; NAM ~44%; and SAM ~64%; globally 66%.

Climate Class per capita (Table 8b). The total Water-withdrawal (mio m³/y) for agriculture compared to the total amount available water is quite high but varies substantially depending on the Climate Classes : for *A ~83%;* for *B* ~85%; for *C* 48%; for *D* ~44%; for *E* ~23%: globally ~66%.

***Table 8b Synthesis : Land use & Water-withdrawal* per Climate Class & per Capita**

				Agriculture area			*Water Withdrawal*	
Climate Zones	Population # Thous.	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

3.2.3 Ratios. Extrapolation to 2100

The ratio of *land for meadows* to *land for crops* and extrapolated to 2100 -in the Table 9a- 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 eventual expanding to crops production, however the apparent advantage disappears with the strong population growth by 2100.

In Table 9b the ratio *Water-withdrawal* for agriculture compared to domestic use shows little reserves for the future.

Table 9a Ratio of land for meadows to crop by 2100

Continent	X = Land ratio meadows/crops 2010	Y= Population growth factor 2015- 2100	Z=X/Y Land ratio 2100
Africa	32.2	2.08	15.5
Asia	16.9	1.15	14.7
Europe	11.6	0.75	15.5
NAM	21.1	1.17	18.0
SAM	59.6	1.30	48.8

Taking into account the population increase, in particular for Africa, there will be considerable shortage, for agriculture as well as for other use. The future situation for Asia and SAM do not look attractive either.

Table 9b Ratio Water-withdrawal agriculture/domestic use

Continent	X = ratio Water-withdrawal/ total. ~2010	Y= Population growth factor 2015-2100	Z=X/Y Ratio Water-withdrawal 2100
Africa	0.827	2.08	0.40
Asia	0.768	1.15	0.67
Europe	0.280	0.75	0.37
NAM	0.437	1.17	0.37
SAM	0.644	1.30	0.50

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 9c 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 ratio is decreasing the fastest where population is the highest, meaning that the potential for transforming meadows land to crops land is decreasing as well. This is particularly the case for the Climate Class *B*, the largest one on earth.

Table 9c Ratio Land meadows/crops : effects of demographic increase.

Class	Population 2010	Population **2100**	Y Ratio Population 2100/2010	X Ratio Land* Meadows/crops 2009	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/Aver.	6,928,068	9,198,253	1.328	-	-

* Values taken from Table 8b

As an intermediate conclusion, without any surprise, the data in the tables 9 to 11 show that the availability of land and fresh water for will decrease substantially with demographic evolution. From these two resources, fresh water is the most critical, it concerns all biological life including human life, as well as the provision of food for humans. A strong enhanced attention, must be given to this situation from all authorities and leaders to this issue, then the survival of many biological species is depending on fresh water.

Chapter 4. Network: Description & Results

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

- the first one, is a graphical tool known as ***Gephi***[33] ***version 0.9.1***, which in the first place provides ***graphical output,*** but also ***statistical data*** about the network. The network diagrams of Fig. 4, 5a & 5b, 6, 7 and 8 have been obtained with it;
- the second one, the use of the statistical software with the program language ***R***[34] and provides different graphical representative of the same networks, Fig 9, 10, 11, 12.

4.1 Applying *Gephi*. Statistical data

Out of the large amount of data some five graphical representations are reproduced here. A complete set tables and graphics will be published in the Volume II.

The five items are:

1. Sequence CZ continents with their countries, Fig 4;
2. Sequence CZ, continents and the rice, Fig 5a-Ri, & wheat, Fig 5b-Whe;
3. Sequence CZ, continents and poultry, Fig 6-Pou;
4. Sequence CZ, continents and four land uses: land for crops Fig 7-LaC;
5. Sequence CZ,continents and water-withdraw. for Fig 8-Wa.

The graphs have all the same structure:

- Red boxes : represent the five Continents : Afri (Africa); Asia (Asia); EUR Europe); NAM (Northern America, inclusive Middle America); SAM, (Southern America, inclusive Australia & New Zealand);

- Blue boxes : three CZs of the *A* Climate Class : Af, Am, AW;

- **Green boxes:** four CZs of the *B* Climate Class: Bsh, Bsk, Bwh, Bwk;

- Purple boxes: seven CZs of the *C* Climate Class : Cfa, Cfb, Cfc, Csa, Csb, Cwa, Cwb;

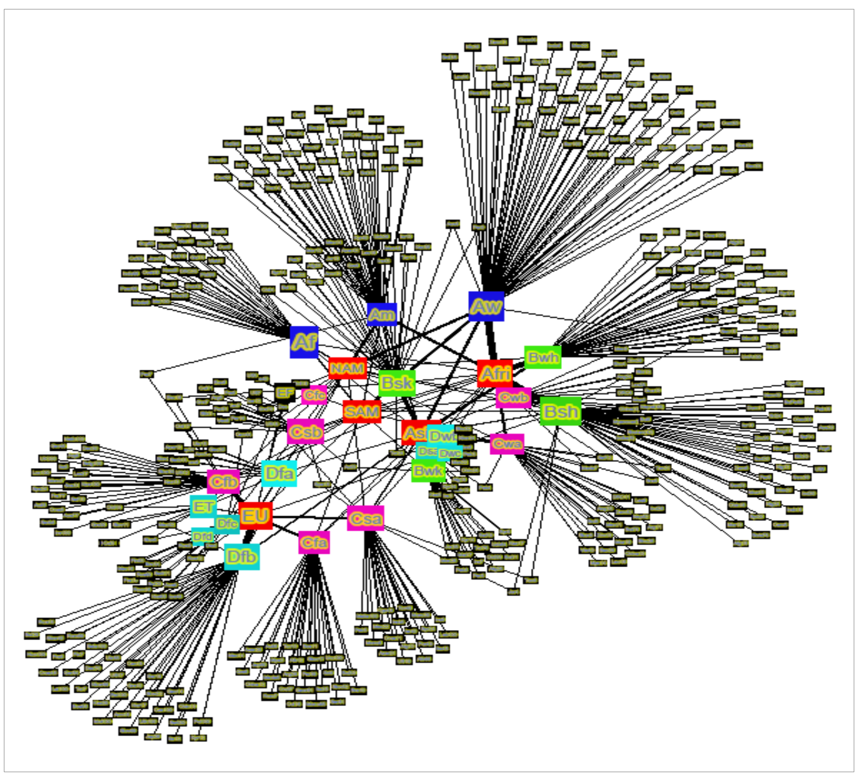
- Blue/Green boxes: nine CZs of the *D* Climate Class Dfa, Dfb, Dfc, Dfd, Dsa, Dsc, Dwb, Dwc, Dwd; and two CZs of the *E* Climate Class : EF, ET.

In total *25* Climate Zones (CZs) are applied.

4.1.1 Continents & Countries and Climate Zones

The graph with the counties of Fig 4 represent a typical structure of the network, namely each CZ is composed by a range or spectrum of countries -in total 150 countries and the fractions of countries -320 fractions of countries-, in total 470 country nodes.

Fig.4. Network for World Countries (150 &320 fractions of countries), CZs (25) and Continents (5) 477 nodes and 543 edges.



The boxes (rectangular or dots) represent the nodes of the network and the lines the edges or links between nodes. In fact it is a rather simple network structure which will guide the further analysis for crops, meat, land for agriculture and Water-withdrawal both for food production.

4.1.2 Crops & Meat Production

In the Tables 5a & 5b (pages 41-42) are the data listed for crops & meat output per continent resp. per Climate Class, and in Table 6a & 6b (pages 42-43) are the same data per capita. The graphical results of the network calculations are shown in Fig. 5A & 5b and Fig 6.

***Graphical Output*.**

- *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 are important 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 mio tonnes by aquaculture[35].

The graphs Fig 5a & 5b represent the world data network for rice and wheat. The structure is similar as for the distribution of the Climate Zones in the countries and fractions in five continents.

Fig 5a-Ri. Network for World Crop Rice, CZs and Continents with 262 nodes and 423 edges (links).

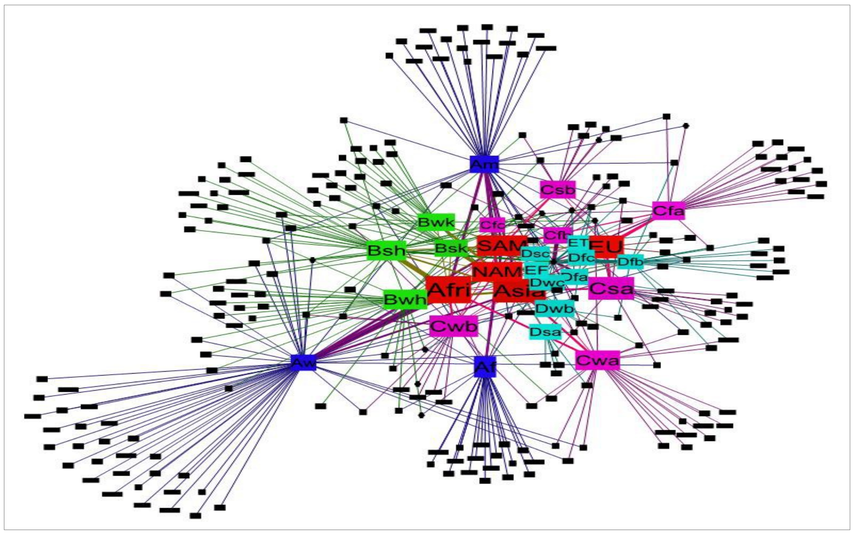
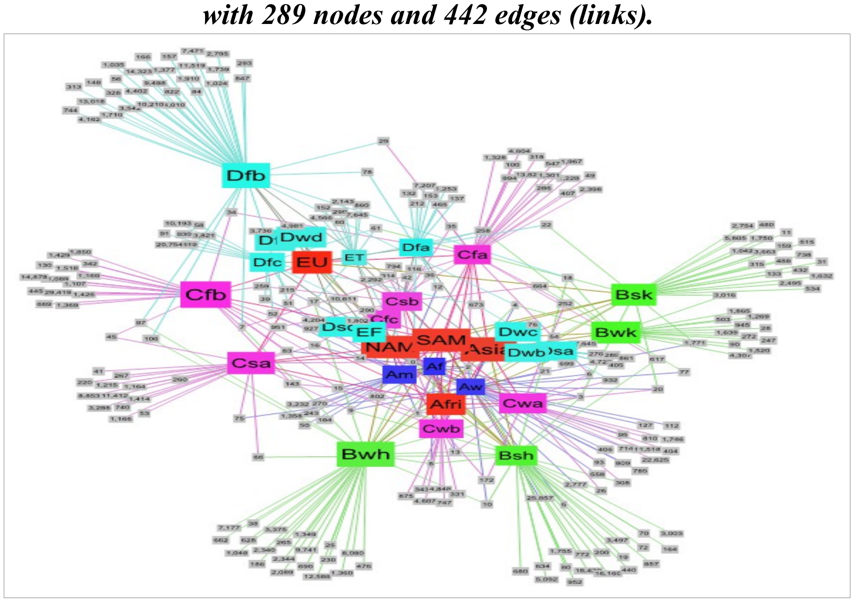
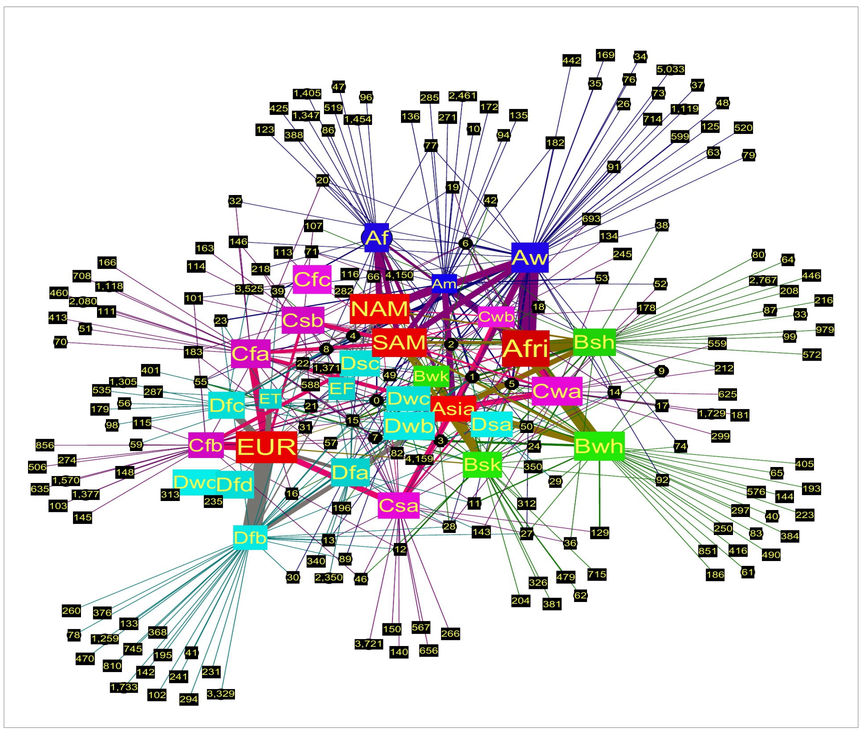


Fig 5b-Whe. Network for World Crop Wheat, CZs and Continents with 289 nodes and 442 edges (links).



The Fig 6-Pou represents the network for world production of poultry, as an example of meat production. The poultry production is well represented in all parts of the world, whereas other meat productions can be influenced by cultural considerations.

Fig 6-Pou Network for World Meat Poultry, CZs and Continents with 280 nodes & 513 edges (links).



4.1.3 Arable Land and Water-withdrawal

- Arable Land

The data express the total available land per continent/ country and per CZ.

The total available land is further divided in: arable land which is

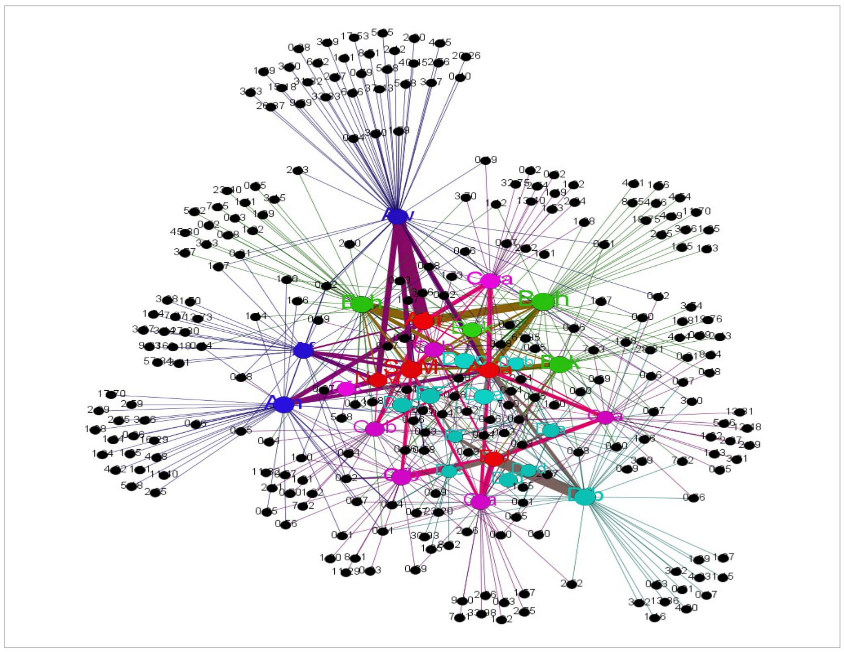
then divided in land for crops and land for meadows/pastures.
Availability in the future of land for food, feed and animal production, including *pasture,* are increasingly a source of concern :

- The built environment, the absence of sustainable urbanization design leads to uncontrolled expansions diminishing available land reserves for 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.

In the Fig 7-LaC is land for crops at world level represented, again showing a similar network structure as the previous ones.
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 approach[36].
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[37].

Forests[38,39]**.** 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.

Fig 7-LaC Network for World for Land for Crops, CZ and Continents with 233 nodes & 476 edges (links).

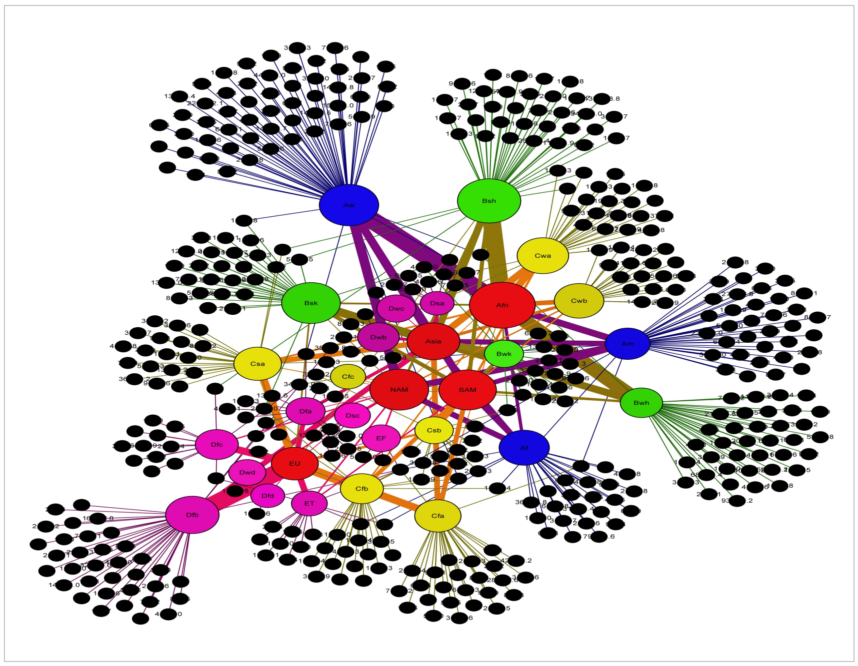


- Fresh Water-withdrawal

Unfortunately in several regions of the planet the surface and phreatic water tables are dangerously polluted as well as their quantities are decreasing rapidly, e.g. California, US.

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.

Fig 8-Wa Network for World Water-withdrawal for, CZ and Continents, with 461 nodes & 542 edges (links)



4.1.4 Statistical[33] values from *Gephi* output

The *Gephi* software provides also statistical data of the graphical representation. These data allow the mutual comparison of the network structure. The results are shown in the two tables below.

> ***Average 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.
>
> ***Average weighted networks*.** Edges can have strength, weight or value, and is represented by a positive number.

Network 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.

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

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 if there are more edges between nodes of the same type than estimated or expected, and negative ones if there are less.

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.

Average 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.

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 single-ton node that is connected to no others has one component of size one, and every node belongs to exactly one component.

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= (# closed paths of length two)/(# paths of length two). The value of c lies in the range of 0 to 1.

The Tables 10a and 10b 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 *Force Atlas2* algorithm.
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[18], will be quite helpful.

Table 10a Network Characteristics Crops-Meat-Land use

	Africa Continent	Asia Continent	EUR Continent	Northern Am. Continent	Southern Am. Continent	Terrestrial Planet
Nodes #	1,207	1,425	1,137	658	858	4,146
Links #	1,553	1,932	1,446	769	1,153	6,320
Ratio Edges/nodes	*1.29*	*1.36*	*1.27*	*1.17*	*1.34*	*1.52*

The number of nodes and links varies among the continents, related to the number of data input. The ratio Edges-Links/Nodes is the highest for the entire planet (1.52) meaning that the number of links is more intensive as compared to each continent separately, and the lowest value for Northern America (1.17) related to a low population density. Globally, the networks resemble quite well.

Table 10b Network Statistical Properties

	Africa Continent	Asia Continent	EUR Continent	Northern Am. Continent	Southern Am. Continent	Terrestrial Planet
Network Overview						
Average Degree	2.573	2.712	2.544	2.337	2.688	3.047
Av. Weighted Degree	3.46	3.214	3.196	2.906	3.063	5441
Network Diameter	4	4	4	4	4	6
Graph Density	0.002	0.002	0.002	0.004	0.003	0.001
Modularity	0.515	0.584	0.559	0.628	0.598	0.559
EdgeOverview						
Avg Path Lenght	3.533	3.726	3.539	3.626	3.669	3.721

Some comments to the above table:
Average degree. Corresponds to c=2*edges/nodes and equals the value calculated in Table 10a. The values are similar for all the cases presented, except for the planet.
Average weighed degree. The value for the terrestrial planet is much higher than the other ones.
Diameter. The diameter of a graph is the length of the longest path between any pair of nodes in the network, and is here 4 for all, except 6 for the terrestrial planet.
Graph Density. $0 \leq \rho \leq 1$, where $\rho = c/(n-1)$. The value is the lowest for the terrestrial planet, in accordance with the value of the diameter. The values are rather small.
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.
Average 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. The values have the same magnitude.

As an intermediate conclusion, the six graphs here displayed -all have been chosen as examples- show a similar structure. They all show how the repartition of products and resources are related to

Climate Zones, as defined by the KG Climate System. Analogous graphs have been calculated for the same parameters but per capita. The demographic increase is evidently a dominant factor in food availability, today and much more by the end of this century. However, the demographic increase does not change the graph structures, but differences among the continents are self convincing, which can also be deducted from the data tables.

The most relevant aspect of these graphs underlines the importance of Climate Zones of the planet. The country boundaries used in the traditional sense of cultural, historical and political entities (several artificially attributed), but not relevant enough, in many cases, for analyzing food production and climate variability. The lack of data, in particular in function of time, has been a limiting factor in the present analysis. As indicated in the text a shift in Climate Zones due to Climate variability and Global Warming is not yet clearly proven. More research is imperative for better apprehending the future.

The values of the statistical data, obtained by the same software tool, indicate once more that the structure of the networks is quite similar for all the cases analyzed so far. Their structure is not particularly complicated, which is apparent from the data tables. The importance of these statistical analysis lies in the fact that the graphical representations are not exclusive visual, but accompanied by mathematical foundations.

4.2 Programming with *R*

The use of the program language ***R***[40,41,42] allows the search for the complementary graphical analyses of the network of production processes. Four specific approaches have been explored : the adjacency matrix calculation, the dendrogram are used in climate model genealogy for surface temperature and precipitation, (Masson D. and Knutti R.), the *Kamada-Kawai* algorithm and decision trees.

4.2.1 Adjacency Matrix[40]

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 are ordered by CZs for the two identities -crops and meat- and their combination, and Land use 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 CZ (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 CZs are with respect to the production of crops, meat, or both and the other parameters, Land use 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 corresponds 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 & 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.* 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 CZs.

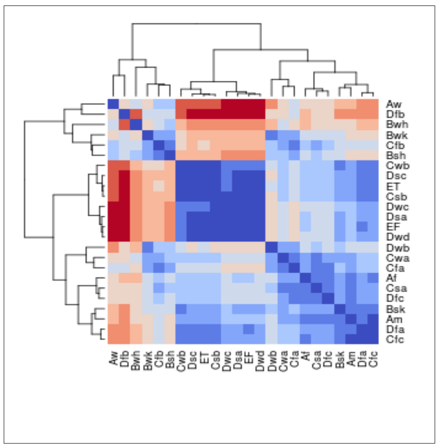
With the help of these connectivity pictures it will be possible to extrapolate potential areas for increasing production as well as to diagnose the vulnerability of the zones in respect with climate change resp. variability.

The diagrams in Fig 9 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 left side of these graphs show the differences more clearly. Similar calculations have been made for crops and the other parameters and will presented in the next volume.

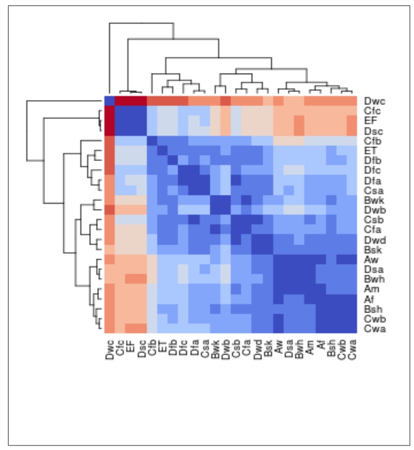
Fig 9 Adjacency Matrix. Meat production

Meat



Climate Zone

Meat per capita



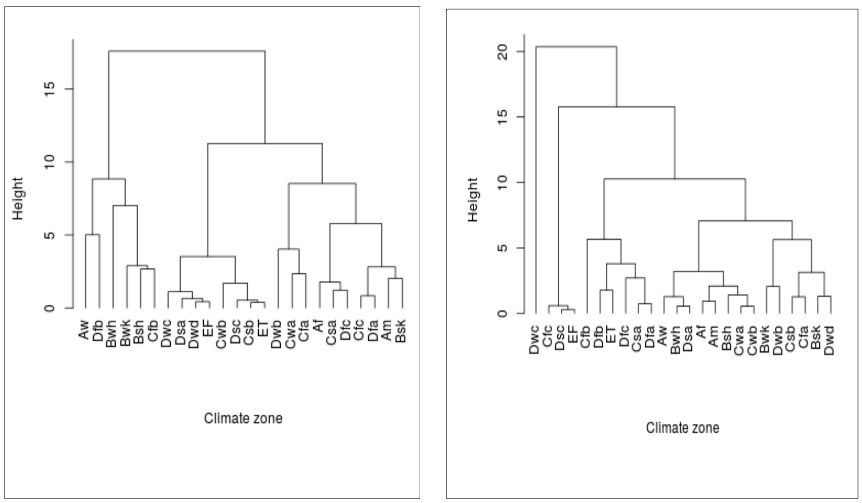
Climate Zone

4.2.2 Dendrogram[41]*. 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 at 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.

Fig 10 Dendrogram Meat production

Meat Production ***Meat Production per capita***



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. This link is said to be *inconsistent* with the links below it.
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 clear in the adjacency matrix of Figure 9.

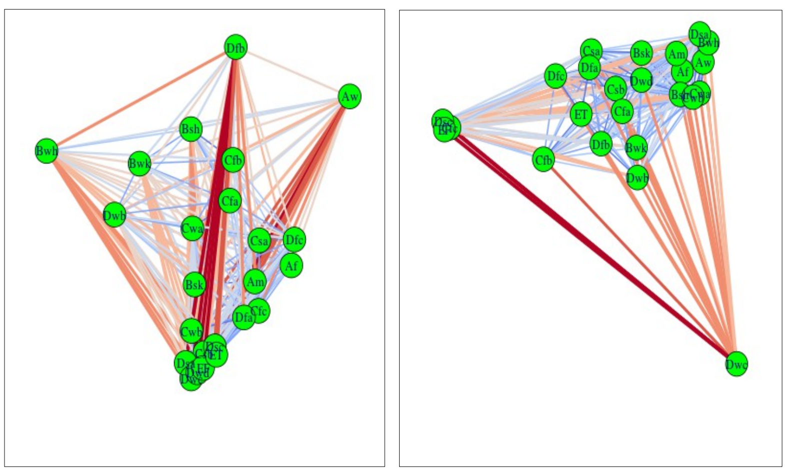
4.2.3 The Kamada-Kawai[42] graphs

A further programming with ***R*** has been done in order to obtain an additional insight in the network structure. The graphical result is shown in the Fig 11 for Meat as with the previous graphs.

These graphs are, in fact, another representation of the adjacency matrix. The nodes correspond with the different CZs. The edges are colored in the same color as used in the adjacency matrix i.e. red means that the distance, or dissimilarity, between the CZs is larger and blue means that the dissimilarity is smaller. The colors are interpolated using a diverging color-map.

Fig 11 Kamada-Kawai algorithm

Meat Production ***Meat Production per ca***



In order to plot the graphs, a force-directed graph drawing algorithm is used. In this algorithm, the distances between the nodes are seen as a force between them. Then an iterative algorithm is used to change the position of the nodes in which they push each other away by the calculated force. Force-directed algorithms produce a graph with minimal energy, in particular one whose total energy is only a local minimum. This means that the resulting graph might not be optimal but it renders good results in general.

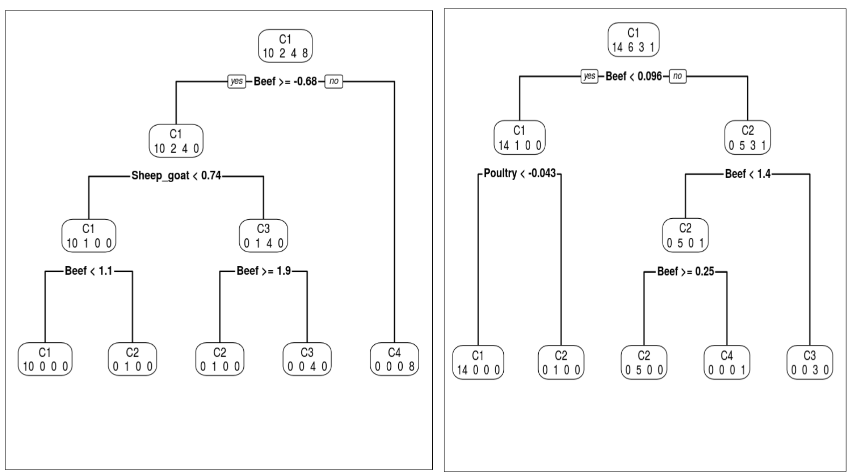
One can see the different clusters, identified in the previous section, by looking at the nodes that are closer to each other. For meat production per capita, this is very clear: Dwc is a cluster on its own and is also drawn as a node much farther away from the other nodes. To the top-left, one can also distinguish the cluster containing Cfc, Dsc and EF. The other two clusters are closer to each other and are not that clearly separated in the graph.

4.2.4 Decision Trees

The hierarchical clustering algorithm is a great way to identify clusters but it does not give any information about the reason *why* a CZ belongs to a specific cluster. In order to investigate this, a decision tree was constructed. This was done as follows : a new column was added to the table, indicating the cluster number to which each CZ belongs. Then, a decision tree was constructed to predict the value of this column, using the information in the other columns. The *rpart algorithm* in ***R*** was used to construct this tree, they are shown in Fig12.
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 ca. The data for the decision tree are summarized in Table 11.
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.

Fig 12 Decision Tree. Meat production

Meat Production	***Meat Production per ca***
C1 : Af Am Bsk Cfa Cfc Csa Cwa Dfa Dfc Bwh Bwk Cfa Csb Dwd	C1 : Af Am Aw Bsh Bsk Cwa Cwb Dsa Dwb
C2 : Aw Df	C2 : Cfb Csa Dfa Dfb Dfc ET
C3 : Bsh Bwh Bwk Cfb	C3 : Cfc Dsc EF
C4 : Csb Cwb Dsa Dsc Dwc Dwd EF ET	C4 : Dwc



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. The size of the CZ Dfd is rather small, and for reason of simplification, this CZ has been added to Dfc. 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.

***Table 11 Decision Tree. Meat production & per ca.* C1 to C4**

		Meat Production				Meat per Capita			
		Beef	Pigs	Sheep	Poultry	Beef	Pigs	Sheep	Poultry
Category	Population # thous.	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**	-	-	-	-

The decision tree gives us an explanation of the similarity between the clusters. For instance, looking at the tree of meat production, one can see that cluster C4 consists of CZs with a low beef production (normalized production lower than -0.68). C1 consists of CZs with a normalized beef production between -0.68 and 1.9 (average too high) and a high sheep-goat production (greater than 0.74). Cluster C1 consists of CZs with an average beef production between -0.68 and 1.1 and a sheep-goat production smaller than 0.74. Finally, cluster C2 consists of CZs with a beef production that is a bit higher than average (between 1.1 and 1.9).

For meat production, one can also see that the members of cluster C2 (Dfb and Aw) are both drawn to the top-right in the Kamada-Kawai graphs. The members of cluster C3 (Bsh, Bwh, Bwk and Cfb) are also drawn close to each other.

The same interpretation can be done for the meat production per capita. In this case beef production is also the most important criterion to distinguish between the different clusters.

Summarizing, these decision trees show that beef production is the main difference between the different CZs when looking at meat production. The other two properties (sheep-goat and poultry) are more similar in all CZs. This representation is a nice way to visualize the different clusters and the distance between them. It shows that the identified clusters have a significant meaning although some clusters are closer to each other, in the Kamada-Kawai graphs.

Some comments about the diagrams.

- Meat Production.

Beef. The first cluster, the production of beef has the value of C4 >= -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 (24 in these calculations).

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. Are not visible in this tree per ca.

In this section a study of the data was made using the ***R*** programming language and algorithms that are implemented in it. The main purpose was to represent the data in another way to gain more insight in the agricultural production and the production per ca. The graphical representations (adjacency matrix and Kamada-Kawai graphs) clearly show there are clusters of CZs that have similar production pattern. In order to identify these clusters, dendrograms were constructed.

These dendrograms confirmed that it is possible to group CZs together in four clusters. Hierarchical clustering was then used to find the said clusters.
However, the clustering algorithm does not give a reason why certain CZs belong to a given cluster. In order to investigate this, a decision tree was built that predicts the cluster number on the 3 different types. As an example the meat production was chosen. On the one hand, the decision trees show that poultry is not a main difference between CZs and beef plays a much bigger role as do sheep/goats. On the other hand, when looking at the numbers per capita, poultry does play a role. But Beef production remains the main characteristic to divide CZs into different clusters.

The hierarchical clustering can also be found in the graph created with the Kamada-Kawai algorithm. So the results can also be made visually clear using graphs. This clearly shows the power of graph representations when trying to analyze complex data, and indicate their usefulness in the search for agricultural production diversity along the CZs.
One can see the different clusters, identified in the previous sections, by looking at the nodes that are closer to each other. For meat production per capita, this is very clear: Dwc is a cluster on its own and is also drawn as a node much farther away from the other nodes. To the top-left, one can also distinguish the cluster containing Cfc, Dsc and EF. The other two clusters are closer to each other and are not that clearly separated in the graph.

Chapter 5. Evolution of Climate Zones up to 2100

5.1 IPCC Approaches

In what follows, extensive use has been made from the IPCC reports[43,44,45,46,47,48]. 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 forcing 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 ecosystems and many human systems to current climate variability. Impacts of such climate-related extremes include alteration of eco-systems, 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 loading 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 KG Classification System. This appears a very difficult endeavor due to the lack 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 period, although some effects are already taking place today.

5.1.1 Emission Scenarios SRES(2000)

United Nations Framework Convention on Climate Change

(UNFCCC), in its Article 1, 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 under-standing 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[43,46] (Special Report on Emission Scenarios, 2000) and RCPs (Representative Concen-tration Pathways, 2013, 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 *story-line* assumes a distinctly different direction for future developments, such that the four story-lines differ in increasingly irreversible ways. Together they describe diver-gent 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 develop-ment, 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 story-line*** 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 story-line*** 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 story-line*** and scenario family describes a *convergent world* with the same global population that peaks in mid-century and declines thereafter, as in the *A1* story-line, 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 story-line*** 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 techno-logical 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 turn-over 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.

5.1.2 Representative Concentration Pathways. RCPs.

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 CO_2 removal from the atmosphere).

Perhaps the most innovative aspect of the RCPs[44,45,47] (2013) 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 12 IPCC-AR5 global warming increase projections (°C)

	2046-2065	2081-2100
Scenario	Mean °C and *likely* range	Mean °C and *likely* 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[48].

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.
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.
RCP6.0. The RCP6.0 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.
RCP8.5. The use of cropland and grasslands increases in RCP8.5, mostly driven by an increasing global population.

5.2 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 *IPCC-AR4 (2007)*[49], which can explain the small and big changes in *A* and *E*.

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*[50] in the tropics. Showing the changes of all the sub-types in the same way as for the major groups.

- ***Class A*** *[Tropical/mega-thermal 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*** *[Temporate/meso-thermal]*. For class *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/micro-thermal 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 Kottek*[51] the 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 KG climate classification. The period was extended by global climate model (GCM) projections to cover the 200-year period 1901–2100.
The projections from five GCMs applied to four emission scenarios defined by the IPCC 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 are selected to calculate world maps of KG climate classes. Both are available on a regular 0.5 degree latitude/longitude grid (3,060km² 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 Center (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 gridded precipitation data-set covers the global land areas excluding Greenland and Antarctica. It was developed on the basis of the most comprehensive data-base of monthly observed precipitation data world-wide built by the GPCC. All observations in this station data base are subject to a multi-stage quality control to minimize the risk of generating temporal homogeneity in the gridded data due to varying station densities.

The extreme scenarios have been selected to demonstrate climate change. The *A1FI* scenario of the SRES[43] report shows the largest shifts, the *B1* scenario the smallest between the main KG climate classes. Values for *A2* and *B2* scenarios are within this range.

Period 1976–2000. This period been analyzed for the global land area : 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.
In the observational period 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.

Period 2076–2100. The SRES emission scenarios, first described in the IPCC Special Report (2000), are a set of 'no-climate-policy' options. The *A1FI* scenario, with emphasis on fossil-fuels (Fossil Intensive), for the calculates projections results in an increased coverage, as illustrated below.
Assuming an *A1FI* 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 (+ increased 0.53%) as well as a decreased coverage of 11.04% of *E* climates (-4.11%) and 19.48% of *D* climates (-2.14 %).

The Table13 summarizes the findings for the 2 periods over 100 year shift, for the land area within the *A1F1* scenario.

Table 13 IPCC SRES A1F1 Scenario for Climate Classes

Köppen-Geiger Climate Class	**Land Area***		**Difference**
	1976-2000 %	**2076-2100** %	%
A	**19.42**	**22.46**	**+3.04**
B	**29.14**	**31.82**	**+2.68**
C	**14.67**	**15.20**	**+0.53**
D	**21.62**	**19.48**	**-2.14**
E	**15.15**	**11.04**	**-4.11**
SUM	**100**	**100**	**0**

*Rubel & Kottek

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.
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 *Chen Deliang* and *Chen W. Hans*[24,25] the KG 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. A very important observation has been made theses authors by indicating that a *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 output; other para-meters like fresh water and arable land availability has to be focused much more strongly.

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*[22] (1993). It should be kept in mind that all mentioned studies look at changes in the KG climate types on the typical climate time scale, which on average is about 30 years.

Although the KG 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 KG 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.*[20] (2007) show the geographic locations of the stations in GHCN2 (Global Historical Climatology Network, version2), 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 dynamic process of global remains within the KG Classification an interesting issue. The process appears to occur much faster than models have intended to evaluate. Recent observations indicate that the global warming evolves pole-wards, and as a recent example the melting of the ice coverage at the Antarctica is much faster than expected. The evaluation of the shift in CZs is therefore important to know. The increase of desertification in Northern Africa, in particular of the Sahara, concerns not only a decreasing surface for habitat of their rising populations, but also a decrease of surface for food production; simultaneously the Sahel is pushed South wards. The construction of a Great Green Wall is a most valuable initiative to help to slow down the progress of desertification in China. as well as in Northern Africa and elsewhere.

Without any doubt the progress of global warming of the planet will be spread over centuries, even the here accepted time horizon of one century is much too short. Indeed it is not enough to look at the emissions of GHG, for the *concentrations* of GHG in the atmosphere are determinant for the global warming process. The RCPs (Representative Concentration Pathways) of IPCC deals with concentration pathways instead of the GHG emission scenarios and can be regarded as complementary to the early

emissions approach defined in the SRES report. The decrease of the concentration of GHG in the atmosphere, in particular of the dominant CO_2, is very slow, unless the emergence of large scale technologies allow absorption of GHGs enabling the decrease at a reasonable speed. Thus the effects of global warming tend to last in a similar way with the evolution of the concentration levels. The threshold values of the CZs are defined in terms of temperature and precipitation, it is expected that changes are essentially driven by temperature.
The applied models indicate common global trends for the 21st century changes across all models[52]:

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

J. Hansen et al.[53] indicated that large warming in 2005–2015 exists not only in the Mediterranean, Middle-East, Sahara region but also in the Gobi Desert and Southwest United States. Amplified warming in desert regions and a tendency for increasing heatwaves and strong droughts to coincide are expected consequences of increased global warming. Gene-rally, as global warming increases, climatic wet regions tend to get wetter and dry regions get hotter and drier. Polar amplification of surface warming is also apparent, but that warming occurs where inter-annual climate variability is very large.

Intermediate conclusion :
Looking into the future concerning the global warming phenomena at planetary scale is quite difficult. The KG climate system is based on two physical parameters average ground temperature and precipitations illustrated in Table 1b (page 32). An average increase of ~2°C does not show a shift from one zone to another.

From thermodynamic[12] considerations the precipitation is correlated to a temperature change and 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.
Several studies have examined the changes of the KG types over the last decades, which revealed a pole ward movement of the KG climate zones, in accordance with the global warming. 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.

Chapter 6 Critical Factors of Food Production

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.

6.1 Weather conditions, temperature[54, 55]

The impact of global warming on the production is a difficult matter. In the Köppen-Geiger classification two major parameters related to vegetation have been introduced: temperature and precipitation. These parameters are listed in the Table 2 (page 35) and refer to the actual situation. To estimate their quantitative evolution over time -the end of this century- is not a simple matter.

~ 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.

> *Period 2030–2049*. Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of the projections for this period 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.

~ 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.

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 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 Center[56], El Batán, Mexico. The Center has 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 straight-forward 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 figure out know what traits to target.

According to *Oxfam*[57] 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 earth-quakes. Between 1980 and 2006, the number of floods and cyclones quadrupled from 60 to 240 a year while the number of earth-quakes 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. Major future rural impacts are expected in the near term and beyond, through impacts on water availability and supply, food security, 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, D. B., Wolfram Schlenker and *Justin Costa-Roberts*[58], 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.

6.2 The Effect on Crops and Livestock Production

***Crops*[59].** Food and feed crop demand will nearly double in the coming fifty 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 high-value crops. FAO projects that the impact of climate change on global crop production will be on the rise 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 the least ability to adapt to climate change or to compensate through greater food imports. In Africa, droughts can have severe impacts on livestock, 1980 and 1999 the mortality in livestock was in large part due to the big impact of severe droughts..
The world **cereal** (e.g. maize, wheat, rice, barley, sorghum, millet, rye and oats) production in 2014 is estimated to reach 2,458 billion tonnes, down by 60.0 million tonnes, or -2.4% from the previous period; see table below.

Table 14 Variations of Crops Production

Crops Type	Amounts 2014/2015	Comparison with year 2013/2014
Cereal	2,458 million tons	a decrease of 60 mio tons;-2.4%
Wheat	702 mio tons	a decrease of 13 mio tons;-1.9%
Coarse grain	1,255 mio tons	a decrease of 52 mio tons;-4.1%
Rice	501 mio tons	up of 4 mio tons; + 0.8%

Coarse Grain World production : cereals without wheat & rice.

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 6ºC above long term means, crop yields dropped significantly, such as by 36 percent for maize in Italy, and by 25% for fruit and 30% for forage in France (IPCC, 2007c). Increased intensity and frequency of storms, altered hydro-logical cycles, and precipitation variance also have long term implications on the viability of current world agro-eco-systems and future food availability.

Livestock*[60]*.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. In the publication of FAO & LEAD *Livestock's long shadow*[61] (2006) it is pointed out that approximately 70% of the world's agricultural land is used by the livestock sector, including grazing land and cropland for feed production. Cur-rent 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 intensive and extensive livestock producers would help to resolve in a more sustainable way 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.

The FAO[61] report assesses the full livestock sector on environmental problems, along with potential technical and policy approaches to mitigation. The assessment takes into account direct impacts, along with the impacts of feed-crop 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. The major sources of pollution are from animal wastes, antibiotics and hormones, fertilizers and pesticides used for feed-crops, and sediments from eroded pastures. Global figures are not available but in the US, with the world's fourth largest land area, livestock is 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.

Although economically not a major global player, the live-stock 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 1/3 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 tons in 1999/01 to 465 mio tons in 2050, and that of milk to grow from 580 to 1,043 mio tons. 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 to urban and peri-urban areas, 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 range-lands, with 73% of range-lands 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 CO_2 equivalent, which is a higher share than for transportation.

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, 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.

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% of annual global crop production. Production from both rain fed and irrigated in dry-land eco-systems accounts for approximately 25%, and rice produced in coastal ecosystems for about 12% (Millennium Ecosystem Assessment, 2005).

6.3 Fresh water : a critical resource

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 antibiotic resistance and many others.

6.3.1 How much fresh water is required?

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 increases. Each person requires a mere 2 to 5 liters of water a day for survival, and 20 to 50 liters 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 liters of water to produce 1 kg of irrigated wheat and 13,000 to 15,000 liters to produce the same quantity of grain-fed beef. Thus, each human being "eats" an average of 2,000 liters 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 to-wards 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 the 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. 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.

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 Center* 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".

To produce enough food to satisfy a person's daily dietary 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. for 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 thermo-cooling- is growing rapidly. Not all water with-drawn 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 the Millennium Development Goals (MDGs) 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 infra-structure and because of restricted access as a result of political and socio-cultural issues.
Per capita food supply in *OECD* countries will level off well above 2,800 kcal/day, 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.

6.3.2 Water availability per continent

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*[62] reveals that one in three people today face water shortages.

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 aggravate water-related problems.

Africa. 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, 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 impacting negatively to affect water resources within the next two to three decades. This will be followed by decreased river flows as the glaciers recede.

In Central, South, East and South-East Asia freshwater availability in particularly 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 the frequency of wildfires.

In *Central and Eastern Europe*, summer precipitation is projected to decrease, causing higher water stress. Forest productivity is expected to decline and the frequency of peat-land 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 out-weigh 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 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 and 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 due to species extinction in many areas of tropical Latin America.

6.3.3 Irrigation: solution for dry areas

In drier areas, climate change is expected to lead to salination 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 and energy generation.

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 should be anticipated. Conservation, precision-irrigated 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 the world community acts to improve water use in agriculture, it will be possible to meet the acute freshwater challenges that humankind is going to face 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 on 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 fresh Water-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 rain fed 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 to irrigate to feed >9 billion people, and while adverse environmental consequences have to be dealt with, 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.

Climate change will affect all facets of society and the environment, directly and indirectly, with strong implications for water and 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.

6.3.4 Evapo-transpiration.

Without further improvements in water productivity or major shifts in production patterns, the amount of water consumed by evapo-transpiration 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 km^3 of today. This corresponds to an average annual increase of 100–130 km^3, almost three times the volume of water supplied to Egypt through the *High Aswan Dam* every year. 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 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.
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 areas under production rather than by expanding them.

- 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 fisheries in many areas.

- In *Sub-Saharan Africa* there is very little irrigation, and expansion seems warranted. Doubling the irrigated area in Sub-Saharan Africa would increase irrigation's contribution to food supply from only 5% now to 11% by 2050.

It is time to abandon the obsolete divide between irrigated and rain-fed agriculture. In the new policy approach rainfall will be acknowledged as the key freshwater resource, and all water resources, 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.

6.3.5 Desalination: coping scarcity of fresh water for food *WWF 2007* and *UNEP*[63,64]. As the world comes to the realization of population increase, development demands and climate change means that fresh-water will be in chronically short supply, in rich and poor areas of the world alike. There is increasing interest in desalination as a technique for tapping into the vast and infinitely tempting water supplies of the sea.

This is no new dream, and it has been technically possible to separate the salt and the water for centuries. But widespread desalination for the purpose of general water supply for land-based communities has been limited by its great expense and it is notable that the area where desalination currently makes by far the greatest contribution to urban water supplies is in the oil-rich and water poor States around the Persian Gulf.

Now, however, improvements in the technology of desalination, coupled with the rising cost and increasing unreliability of traditional water supplies, are bringing desalinated water into more focus as a general water supply option with major plants in operation, in planning or under consideration in Europe, North Africa, North America, Australia, China and India among others.

FAO 2006[65]. With worldwide concerns about water scarcity, agriculture is under pressure to improve water management and explore available options to match supply and demand. Desalination is a technical option to increase the availability of freshwater both in coastal areas with limited resources and in areas where brackish waters -such as saline ground-water, drainage water and treated waste-water- are available. Desalinated water can also be crucial in emergency situations where water sources have been polluted by saline incursions. However, desalinated water produced worldwide, estimated at 7,500 million m3/year, equals only 0.2 percent of total water use.

Water desalination[66] is a well-established technology mainly for drinking-water supply in water scarce regions such as the Near East. However, with accounting for 69% of all water withdrawals compared to domestic use of about 10% and industry 21%, it is the main source of potable water in the Persian Gulf countries and in many islands around the world and it is also being used in certain countries to irrigate high-value crops. However, it has proven much less economic for agricultural application than the reuse of treated waste water, even where the capital costs of the desalination plants are subsidized.

Because of the increasing awareness of water desalination potential as an additional source of water for agriculture, questions the fundamental economics of its application. FAO has organized an expert consultation on "*Water desalination for agricultural applications*" to analyze and examine the long-term prospects.

According to new data from the *International Desalination Association*, the amount of new desalination capacity expected to come online during 2013 is 50% more than last year's total. Desalination plants with a total capacity of 6 million cubic meters per day (m^3/d) are expected to come online during 2013, compared with 4 million m^3/d in 2012. Industrial applications for desalination grew to 7.6 million m^3/d for 2010-2013 compared with 5.9 million m^3/d for 2006-2009.
The markets which are expected to see the fastest growth in desalination over the next five years are South Africa, Jordan, Mexico, Libya, Chile, India, and China, all of which are expected to more than double their desalination capacity. The new capacity could produce the same amount of freshwater as falls on London in 28 months or 19 months of rain on New York City. It takes the total capacity of all 17,277 commissioned desalination plants in the world for 80.9 million $m^{3/}d$. The installed capacity in Southern Europe is 4,405,024 m^3/d. This figure includes all source water

types. Seawater desalination accounts for most of the production in Southern Europe, brackish water for about 1/4 of the production and waste water desalination plays a relatively minor role.

A recent report of the OECD[67] treats the problem of water availability in cities. Too much, too little or too polluted? More and more, this characterizes the key water challenges facing cities. Projections show that nearly 20% of the world's population will be at risk from floods by 2050, while several cities are already suffering from the consequences of heavy droughts, even in water-rich countries such as Brazil (OECD, 2012a; OECD 2015c). Many cities are suffering floods and droughts at the same time, which requires robust governance to move from crisis to risk management and resilience.
The use of water in metropolitan areas is affected by decisions taken in other sectors and vice versa, in particular, energy, finance, solid waste, transport and land use. There is a need to ensure that water is recognized as a key factor of sustainable growth in cities. Such a strategic vision is essential for strengthening policy coherence for an integrated urban water policy, mitigating split incentives whereby those generating future liabilities do not bear related costs, and fostering a whole-of-government approach that builds on horizontal and vertical co-ordination.

6.4 Fertilization

6.4.1 Greenhouse fertilization

Higher levels of atmospheric CO_2 concentrations stimulate plant growth, the so-called *greenhouse fertilization*[68] *effect*, is expected to produce local beneficial effects. 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 photo-synthetic efficiency (C4 crops), assuming that CO_2 levels in the atmosphere reach *550 parts per million* (IPCC, 2007c); these effects are not likely to influence projections of world food supply.

The impacts of mean temperature increase will be experienced differently, depending on location. For example, moderate warming -increases of 1 to 3ºC 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 3ºC is expected to have negative effects on production in all regions (IPCC, 2007c).

6.4.2 Mineral fertilization

The introduction of mineral fertilizers has led to the dramatic increase of the production of crops and vegetables. The so called green revolution has been the result of systematic use of three fertilizers. Mainly it concerns *nitrogen* in form of urea, ammonium sulfate, ammonium nitrate; *phosphorus* in form of diammonium phosphate, calcium phosphate and *potassium* in form of potassium chloride, -sulfate and mixed with magnesium sulfate, -nitrate. For potassium and phosphorus, these components have to be extracted via mining and evaporation of sea or ocean waters.

Their availability is in fact crucial in view of increasing demand of output.

For ***nitrogen*** there is no fear of shortage since the atmosphere contains more than can be consumed.

For ***potassium***[69] there appears no direct concern for shortage in the medium to long term and will not be further investigated here.

For ***phosphorus***[70]***,*** on the contrary some concern about scarcity has been reported in the literature, which according to some authors could become a major problem by the end of this century. In what follows more attention will be given to this essential resource for food production in the coming decades.

The case of Phosphorous. *UNEP Year Book*[68], virtually every living cell requires phosphorus, the eleventh most abundant element in the Earth's crust. However, the soil from which plants obtain phosphorus typically contains only small amounts of it in a readily available form. So far, there has been no known substitute for phosphorus in agriculture. If soils are deficient in phosphorus, food production is restricted unless this nutrient is added in the form of fertilizer. Hence, to increase the yield of plants grown for food, an adequate supply of phosphorus is essential.

Farming practices that are helping to feed billions of people include the application of phosphorus fertilizers manufactured from phosphate rock, a non-renewable resource used increasingly since the end of the 19th century. The dependence of food production on phosphate rock calls for sustainable management practices to ensure its economic viability and availability to farmers. While there are commercially exploitable amounts of phosphate rock in several countries, those with no domestic reserves could be particularly vulnerable in the case of global shortfalls

Phosphorus has received only limited attention compared to other important agricultural inputs such as nitrogen and water. Because of the vital role of phosphorus in food production, any consideration of food security needs to include an informed discussion concerning more sustainable use of this limited resource.

Key themes include the increasing global demand for phosphorus fertilizers. There is an ongoing debate over the long-term availability of phosphate rock, lack of adequate phosphorus accessibility by many of the world's farmers, prospects for increased recycling and more efficient phosphorus use in agriculture, and minimization of losses through soil erosion control. More detailed research is required to provide reliable, global-scale quantification of the amount of phosphorus available for food production. A global phosphorus assessment, including further insights from scientists and other experts, policy-makers and stakeholders, could contribute to improving fertilizer accessibility, waste management in urban settings, and recycling of phosphorus from food waste and from animal and human excreta.

Preventing humanity from food scarcity, some substantial changes in the management and use of phosphorus are needed with projections over several decades. Presently, 50% is wasted in the food chain between farm and fork, 30 to 40% is lost during mining and processing, only 20% of the phosphorus in phosphate rock reaches the food consumed globally, and only half of the manure is recycled back into farmland around the world. Additionally, most of the wasted phosphorus enters our rivers, lakes and oceans resulting in eutrophication, this emerging as a serious form of water pollution[70].

In the Report to The Club of Rome *Extracted* (2013), Ugo Bardi[70] and the publication of Cho Renee[71] of the Earth Institute, Columbia University, demonstrated clearly the concern of the availability of sufficient phosphorus for agriculture. "*The lack of phosphorus, if not countered by radical changes in the way modern agriculture is managed, could be a true Achilles' heel of our society"*(page 162 in U. Bardi's book).

Given that there is no alternative to phosphorus, it can be considered as life's bottleneck. Most mined phosphorus must be converted to a soluble form before it can be used as a plant fertilizer. The main producers today are China, US, Morocco and Western Sahara, Russia, Jordan and Brazil. Worldwide there are large phosphorus deposits (300 billion tons) but the vast majority are difficult to access and expensive to extract. Predicting the peak production is difficult to evaluate, some calculations suggest that the peak production might occur by mid century, however the degree of uncertainty remains quite high due to the lack of sufficient data.

Up to now, there are no international organizations or regulations that manage global phosphorus resources, how-ever our ability to feed humanity will depend on how human society manages the phosphorus resources. The long-term availability of phosphorus for global food production is of fundamental importance to the world population. Given the diversity of issues surrounding phosphorus, only an integrated set of policy options and technical measures can ensure its efficient and sustain-able use. There is a need for accurate information about the extent of global reserves, new technologies, infrastructure, the right institutions, attitudes and policies to meet the challenge of sustainable food a rapidly growing global population while maintaining a healthy and productive environment.

6.5 Soil structure and soil quality

Soil quality is an increasing concern among researchers as Bourguignon Cl. & L[72,73] of the LAMS laboratory The over-use of biocides -pesticides, fungicides, insecticides a.o.- have resulted in the elimination of biological life of the soil. The consequences are multiple and lead to 'dead soils', having lost their mechanical structure necessary for growing plants but enhance increasing erosion due to the disappearance of roots in the soils structure. Indeed some biocides contribute directly to the destruction of the root system, resulting in the long term of biological lifeless soils.

Food web complexity is a factor of both the number of species and the number of different kinds of species in the soil. Complex ecosystems have more functional groups and more energy transfers than simple ecosystems. The number of functional groups that turn over energy before the energy leaves the soil system is different and characteristic for each ecosystem. Land management practices can alter the number of functional groups – or complexity – in the soil.

6.6 Soil Erosion[74,75]

Soil erosion occurs on two different ways : water and wind erosion. High soil erosion rates will have significant negative effects over longer time spans: the loss of topsoil will result in a reduction in the soil's capacity to provide rooting space and, more importantly, in the capacity to store water that can be released to plants. This may reduce soil productivity. However, these changes occur relatively slowly: the reduction in water holding capacity and/or root space accommodation results in yield declines of ~4% per 0.1m of soil lost. Except for areas where *erosion rates* are very high (e.g. exceeding 50 tons/ha/yr or ca. 4 mm/yr) this means that effects of erosion on crop productivity will be relatively small on the decennial or centennial time scale, provided that nutrient losses due to erosion, are compensated. Over longer time spans, however, the effect of these losses becomes very significant.

Water erosion. Soil erosion by water induces annual fluxes of 23-42 Mt (megaton) Nitrogen (N) and 14.6-26.4 Mt Phosphorus (P) of agricultural land. These fluxes may be com-pared to annual fertilizer application rates, which are ca. 112 Mt for N and ca. 18 Mt of P. These nutrient losses need to be replaced through fertilization at a significant economic cost.

Wind erosion winnows the finer and more chemically active portion of the soil which carries bio-geo-chemicals, including plant nutrients, soil carbon and microbial products. Some of this eroded sediment is deposited relatively close to field boundaries, often much of it enters into suspended mode and may be

transported high in the atmosphere to travel great distances. This long-range transport of dust produces effects at the global and regional scales. Atmospheric dust produced by wind erosion profoundly influences the energy balance of the Earth system by carrying organic material, iron, phosphorus and other nutrients to the oceans.
Well known examples are the Dust Bowl in the nineteen thirties in the US, and today's initiatives to prevent wind erosion with planting the Great Green Wall in China and the Sahara and Sahel Great Green Wall in Africa.

6.7 The Bio-fuel challenge

Using the output of human food as an alternative energy source -bio-fuel[76] will become a real challenge. These vegetable sources -wheat, maize, sugar cane, a.o.- used for energy will become increasingly or are already to some extent, in competition with soil for food and fresh water and are indirectly at the basis of the elimination of forests and their services: carbon dioxide fixation, bio-diversity, etc. According to *Reading Soil Science*[77] in 2010 the ethanol production will consume 15% of global grain production and 30% of global sugar cane production; bio-diesel 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 for the human species. Political and societal leaders have the responsibility to handle 'nature' wisely in the interest of the survival of the human species.

Chapter 7. Feeding the World Population: feasible options

Climate change will make it increasingly difficult to feed the world population. Bio-tech crops will have an essential role in the future, ensuring that there's enough to eat.

7.1 Breeding. The work by *Norman Borlaug*[78,79]

Norman Borlaug introduced several new and revolutionary innovations.

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

-*Second*, he crafted the 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 of 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 or an overall raise of a factor of 2.4.
India is an excellent case in point. In the pre-Borlaug period, 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: 1lb= 0.45kg and 1 acre=0.40ha). 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/ha (6000 lb per acre) or a factor of 7.5.
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 1.72 times.
Without the high-yield wheat variety, 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.

7.2 Photosynthesis C3 & C4[80]. The case of Rice

Dan Voytas[81,82], 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 photo-synthesis, rather than the more complex C4 version that corn and sugar-cane have. 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.

Adapting crops cannot be separated from other management options within agro-ecosystems. For example:
Rice is both affected by Climate change and has an effect upon it. 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 it 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 one 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 2 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 dry-land conditions, minimize post-harvest losses, and have in-creased resistance to drought, 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 2004 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 crop-ping systems in Asia, RICMS, could complement the introduction of new varieties and could address the environmental problems that have emerged in these systems (International Rice Commission, 2002).

IRRI[83,84] 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 is, head-quartered in Los Baños, Philippines. *Science of C4 Rice. Value proposition. (*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 CO_2 per unit of water lost. C4 plants are able to do this because of the compartmentalization and concentration of CO_2 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 (catalyst) that fixes CO_2 into sugars. By requiring less Rubisco for the same amount of CO_2 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 sup-port yield increases of 30% to 50% based on comparative studies between rice and maize.

7.3 GMO perspectives

- Endogenous GMO[84]

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 will not 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.

- Exogenous GMO. Transgenic Crops.

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. 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.

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 sometimes 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.

UCS[85]. Union of Concerned Scientists. *Failure to yield. Evaluating the Performance of Genetically Engineered Crops*

The burgeoning human population challenges 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 the 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 waste can improve yield by over100 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 sufficient when measured on a global scale, ample production for 9 or 10 billion people poses a challenge. The producing of enough food while minimizing the environmental harm, remains a difficult objective. The progress of the global warming phenomenon adds to the necessity for action.

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%, despite projected population increases of about 50%; 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 7.0-10.0 kg of grain are required to produce a kg 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.

Up to now, 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 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 promising 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.

7.4 Agricultural production: Global warming and Demography

-*Much more people to be fed.* 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 US in 2012 yields of corn were down 20%, the year not being unusual as per what the climate model predicted.

Wheat is also emblematic of the struggles facing 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 bio-technology 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[86], deputy director of the Center on Food Security and the Environment 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 in the Indo-Gangetic Plain, the home of nearly a billion people.

- *Global Warming effects in Climate classes/zones.* 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. Impacts from climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability.

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. Impacts of 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. For example, Climate Change has negatively affected wheat and maize yields for many region. 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.

Chapter 8. The way to action. Recommendations

8.1 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, climate and weather conditions and socio-cultural habits. In all cases they determine the survival of human societies in vulnerable places. To end hunger on a global scale, has been a quest tat has plagued the human society for many centuries, but 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 patterns.

Quoting ***Norman Borlaug***, cited in the *Scientific American*[87] by David Biello on September 14, 2009 :

"… civilization as it is known today could not have evolved, nor can it survive, without an adequate food supply..."

"The first essential component of social justice is adequate food for all mankind."

However, the economical-technological evolution has been 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 the recognized phenomenon of *Climate Change* and the embedded Global Warming.

Both phenomena have cumulative effects in particular on food production, raising the question 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 25 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 under-nourished of the present day of <1 billion people. Special attention is given to the African continent, for the increase of the population with housing, health care, capacity building[29], education, infrastructure, remain herculean tasks.

– The use of recent *Network Sciences* and elements of the *Graph Theory*, have allowed formulating of the inter-linkage of essential parameters -crops and meat production, land use and fresh water availability for 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 data covers three crops (rice, maize, wheat), four meat types (beef, pork, sheep, poultry), Land for agriculture and fresh Water-withdrawal, 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 taken into account. 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, a fact one has to recognize as a dramatic failure of the human species. This 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, given the fact that all our previous attempts to feed the world have remained unsuccessful.

The long term scale is an enormous obstacle for action in this complex phenomenon. The impact of global warming on 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 a concern of human societies, however no individual or community can escape the effects of climate variations, and every individual has to eat for survival and perpetuation of the community the individual belongs to. However history has clearly shown the degree of difficulty to cope with these challenges, or more clearly to come up with long term sustainable solutions.

The vision expressed here is an attempt by making use of,
first, of the new scientific investigation methods of the *New Science of Networks*, which will be helpful for over-coming local interests and situations, and stimulate global decisions for long term actions; and,
second, of the *Köppen-Geiger Climate Classification System* as a system liberated from historical and frequently arbitrary country borders.

The present findings are addressed to all individuals on Earth, in particular to the leaders of civil society and to the political leadership of local, regional, national and inter-national bodies, to all individuals -scientists, sociologists, economists and many others, concerned about our species and its future. Indeed, we are living an extra-ordinary period

in human history, but facing exceptional challenges for the long term as well.

8.2 The Ethical Dimension

The food availability for all is much more complex than ever considered. Food is the basis of the human value scale, it is simply existential. The *ethical dimension* of the food problem has been indirectly addressed all along this analysis.

The agricultural production as been all along history and all over the planet, precarious. In recent centuries that situation has changed, however not in a systemic way. The techno-scientific knowledge accumulation has allowed to increase the production of food and succeeded to boost the efficiency of crops and animal husbandry production, due to the use of breeding experiments with crops and animals, application of mineral fertilizers, the extension of irrigation, and other. Of course humans had already, along the history of agriculture, improved the productivity. The additional techno-scientific knowledge has privileged dominantly industrialized societies. Today almost a billion people suffer malnutrition, which corresponds to ~10% of the world population. These amounts are known for decades, however no political or societal institutions have succeeded to eradicate this situation. The increase of the world population during this century and the additional impact of global warming on the food production are enormous challenges for the human species. In order to cope with this fast increasing situation, the question arises how to apply a worldwide human value system, which has the strength of overarching local habits and cultures, as well as philosophical and political differences. In fact, given the cumulative threats of demography and global warming a ***strong ethical consciousness*** has to emerge, which appeals to a general ***responsibility*** of leaders at all levels of the human society. Indeed the ***techno-scientific*** accumulated knowledge and the ***world ethical value system*** have to go hand in hand. This converging approach appears to be unique in history, indeed it deals with the survival of the human species.

8.3 Recommendations. Avoiding Planetary Food Scarcity

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 the food 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 positioned within existing world institutions or created, out of immediate urgency. The need for large scale, above all holistic, investment over several decades would belong to the mission of such a body.

In fact the question is again, if a world governance and a 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 an overarching approach.

The Existential Priority of the Human Species.

Allocating the highest priority to planetary agriculture.
Its priority *cannot* be disconnected from : planetary Climate Change remediation, availability of fresh water and fertilizer resources,

and

a specific *world governance body for investment in agricultural production* should be envisioned, in order to avoid massive social unrest and political instability in several regions on Earth and over several decades to come.

Given the existential importance of food availability, a number of realistic proposals are formulated here. Indeed, they are realistic, however, not easy to translate into practical actions, for many require long term policies trespassing local or national borders and political habits.

⇒ 1st Management of fresh water, biological soil quality and fertilizer resources have to become the highest priority within the food production.

Water-withdrawal for agriculture is by far the largest user of fresh water, 75% of the total Water-withdrawal is used for food 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, eventually with external knowledge input and investment..

Climate variability and extreme weather phenomena increase the difficulty of the management task seriously, however there is no alternative. It has been stated that water management needs to become the highest priority for sustaining and expanding agricultural output.

The dependence of food production on phosphate rock calls for sustainable management practices to ensure, in the long term, its economic viability and availability to farmers. The stock is **not unlimited**.

⇒ 2nd It is proposed that some of today's land for meadows and pastoral use are converted to land for crops.

Land for agriculture. The use of the land area for meadows and pastures compared to land for crops is many times higher and varies from 5 to 20 times, depending on the geographical area.
Obviously the conversion should be practiced in areas which are potentially 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, for example pastoralists habits and cultures. The conversion will take time to get these soils adapted for crops production. However, one should keep in mind that the soils used today have been adapted for crops production through human labor and intervention.

⇒ 3rd Crops production. Breeding remains an exceptional process for enhancing food production.

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

⇒ 4th GMO. Endogenous genetic modification bear the necessary efficiency for plant production improvements.

GMO. Genetic Modified Organisms have been applied for several decades. Two types of genetic modification are in use : endogenous an exogenous genetic plant intervention.

– ***endogenous*** genetic modification consists in modifying internal plant processes without involving external input. These techniques seem to be very promising. Moreover endogenetic 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.

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

⇒ 5h Photo-synthesis. Extension of higher GHG uptake and resistance to drought through specific improvements of photosynthesis.

From C3 to C4. 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 Industrialization of animal husbandry, in particular for beef, is advantageous, for it requires less land use allowing increased surface for crop production, however it alienates humans from the bio-sphere further.

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 industrial husbandry practices of pigs and poultry are already in use. Introducing these practices in beef and dairy production, allows the increase of land for crops, however, the land use and Water-withdrawal for feed production remains the same

⇒ ***7th Massive investment in agriculture is a must for Africa, allowing small scale mechanization for local food production. Capacity building belongs to the investment process.***

African continent. Among the different continents analyzed, the African continents 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 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 framers as well increased *capacity building* necessary for the efficient use of the invested equipment.

⇒ ***8th Producing bio-fuels from food & feed is entirely unsustainable and must be discontinued immediately.***

Bio-fuels. The concept and the practice of producing *bio-fuels* 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 fresh water resources, very much needed for human consumption. Last but not least, it has a tremendous ethical dimension.

⇒ ***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.***

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 additional billion individuals, plus the still undernourished of about one billion people. The expected increase of meat consumption 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, resulting in some -estimated- five billion people. The Climate Change through *global warming* and *extreme weather* conditions, enhance the need for an overarching governance approach or institution. ■

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, and to all people concerned about the future of our society.

The **ethical dimension** ***requires that all persons have the right to have enough daily food for themselves and their families.***

&

Top-Priority

Allocating the **highest priority** ***to*** **planetary** ***agriculture on*** **all** ***political and humanitarian agendas.***

This priority **cannot** ***be disconnected from : planetary*** **Climate Change remediation,** ***availability of fresh water, sustained soil quality and fertilizer resources.***

A specific **world governance body** ***for agricultural investment and production should be envisioned, for preventing massive social unrest, violence and political instability over longer periods in several regions on earth.***

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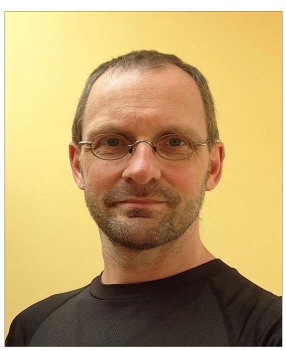

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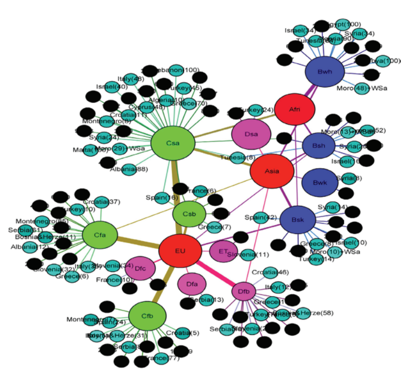
Food Scarcity
Unavoidable by 2100?

Impact of Demography & Climate Change

The planetary food production, although practiced since millennia, is quite complex. Holistic approaches are indispensable, however difficult to realize. Novel elements are used: the Köppen-Geiger Climate Classification System, the Graphical Network descriptions & related statistics, the demographic increase, with the focus on specific continents, the impact Climate Change on agriculture.
Nine recommendations are suggested for coping with the existential challenge of feeding all humans by the end of the century. Among them, the creation of a world governance body, acting over several decades, for dealing with the feeding of the world population.



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