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# Climate Services: Their Potentials in Improving Economic Performances in Agricultural Systems

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## ***INTRODUCTION***

Nowadays adaptation to Climate Change represents one of the main problem contemporary society has to face with, especially because of the high complexity characterizing the socio-ecological systems and therefore the related problem solving.

The difficulty to manage climate variability is particularly relevant in the agricultural sector, in which key challenges are related to the behaviour of economic agents and their relationships, within the broader context of climate change adaptation.

To understand how these interactions take place, represents an open and stimulating issue for decision-makers and socio-economic research units.

Generally we can distinguish between two different types of adaptation.

Planned adaptation refers to a policy context, in which decisions take the form of identifying the “best option” within sets of different plausible adaptation measures.

Autonomous adaptation instead concerns economic agents’ behaviour, by exploring their decision processes and preferences and analyse effects at multiple scales. In such a context, to analyse and well understand interactions among different agents in contest-specific situations become fundamental, building mental models able to extricate the intrinsic complexity of the system.

Which is the potential role that climate services may play? In particular, to what extent and by which tools they could improve climate information so that these may be efficiently managed and utilised to contribute to water saving and to perform as well agricultural practices? And how all these considerations fit into the context of climate risk management?

Agent-Based Modelling constitutes one of the more suitable methods in approaching these problems, being able to capture the intrinsic complexity of socio-ecosystems and, in this manner, leading decision-makers into the right way to operate across these systems.

This thesis starts first focusing on climate change empirical evidences, based on IPCC AR4

studies (chapter 1).

Chapter 2 deals with the key role played by adaptation to climate change, while the third chapter presents climate services as the crucial instrument to address information into the right way to manage related problems (chapter 3).

Finally, after having presented in chapter 4, ABMs as one of the principals methodologies to approach in different ways adaptation to climate change, my dissertation aims to explore some socio-economic potentials of climate services in adaptation to climate change, referring in particular to a case study concerning the implementation of ABM in agriculture field (chapter 5).

## **CHAPTER 1**

### **THE AWARENESS OF A NEW GLOBAL PROBLEM: CLIMATE CHANGE AND ITS IMPACTS ON SOCIO-ECOSYSTEM**

On the wave of the considerations given in the last decades by some of the major institutes involved in climate analysis and research (IPCC, WMO, UNEP, etc.) we can affirm with enough certainty that climate change and its governance represents one of the main problem that will have to be manage during this century. These thought is also confirmed by several political institutions, like for example UE that place environment protection and sustainable development among the most important actions to undertake inside the Union policy in recent years and for the future too.

Of all the environmental issues emerged in the past few decades, global change is probably the most serious because of the severity of contents that it might bring; even if technology became to date more important for our society, we can' t forget that many aspect of human society and well-being still depend on a relatively benign range of climatic conditions.

Climate change projected for the 21<sup>st</sup> century are much larger than twentieth-century variations and their human impacts are likely to be correspondingly greater. Of course these projections are uncertain, but uncertainty consequently makes the issue more serious, not less; in this sense climate changes might turn out to be smaller than we now project, but larger too.

In addition to being probably the most serious environmental problem we have yet faced, climate change will also be the most difficult to manage. In fact environmental issues often carry difficult trade-offs between the key variables they involve; furthermore political conflicts are frequent in this field and, in terms of costs, the capitals required are very high and generate opposition.

Climate change is a phenomena that is harder to evaluate because the activities causing it

(mainly burning fossil fuel for energy) are a more essential foundation of world economies (fossil fuel provide nearly 80 percent of world energy supply) and no technological alternatives are now available to replace this source quickly or cheaply. So, climate change carries higher stakes than other environmental issues both in severity of potential effects associated, and in the cost and difficulties of reducing climate changes.

In the next paragraph, according to IPCC Fourth Assessment Report on Climate Change, some of the most relevant evidences on climate change are exposed while, the second part of this chapter, treats about the implications of climate change issues on socio-ecosystems, always referring mainly to the definitions given by IPCC AR4.

### ***1.1 Inside Climate Change***

Starting the discussion about climate change problem, first it is important to define its meaning. People classify the climate in many different ways depending on who needs the information, how much they know about the climate system and what information they need to know.

It is important to highlight that, while climate refers to average meteorological conditions, weather refers to meteorological conditions at a particular time. So, weather matters for short-term decisions, instead climate concerns the long-run.

The definition of Climate Change given by Intergovernmental Panel on Climate Change refers to a change in the state of the climate that can be identified (e.g. 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. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly

to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods<sup>1</sup>.

So, in general the climate of a place, a region, or the earth as a whole, is the average over time of the meteorological conditions that occur there, the average weather.

Global climate change came to the attention of policy-makers after decades of related scientific research. Only during the energy-policy debate of the 1970s it was clear that human activities had the potential to change the global climate, even if were not clear in which direction. In the early 1980s became increasingly clear that warming from greenhouse gases was the predominant concern, and scientific organization began trying to persuade governments to pay attention about the climate problem; in these years Intergovernmental Panel on Climate Change (IPCC) was established and governments also began considering concrete measures to face climate change.

Through 1991 and 1992, national representatives worked to negotiate the first international treaty on climate change, the Framework Convention on Climate Change (FCCC), that entered into force in 1994 with the objective of “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate system...within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner”<sup>2</sup>.

The creation of the United Nations Framework Convention on Climate Change (UNFCCC) represented a starting point for more specific and binding measures to be negotiated later; at these point in fact only few governments made serious efforts to meet the fixed goals.

Several negotiations started in the next years and culminated in the signing of the Kyoto

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1 Definition of climate change given by IPCC AR4, p. 30.

2 From UNFCCC Convention, article 2.



Protocol in December 1997, with the aim of reducing CO<sub>2</sub> emissions. However, after these agreement, an accord about emissions' reduction was not complete yet; on the contrary after the initially signature and many negotiations, USA reject the treaty in 2001. The protocol finally entered into force in February 2005 after Russian signature, but the accord continues to date to create threads within the global community committed in climate warming field. Also by the emphasis on climate warming highlighted by IPCC in 2007, confirming the growing scientific consensus about climate change problem, taken actions remained dimmer, and the 2009 Copenhagen Accord too, is based on voluntary basis from individual nations rather than a binding international treaty.

Summarizing, the debate occurred in the last decades in climate change arena, jointly to the continuous and multiples transformations that take place in approaching the governance of climate issues, clearly show the difficulties to manage environmental matter and climate change in particular. These difficulties are also confirmed nowadays by actual studies and researches; that's why climate change management is, to date, one of the main contemporary challenges.

### *1.1.1 Actual Climate Change*

About actual climate change conditions and future long-term scenarios, probably the main document in providing information is represented by IPCC, with its Fourth Assessment Report (AR4) on Climate Change, 2007<sup>3</sup>.

The IPCC is a scientific body and today 194 countries are members of this body. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. Thousands of

3 The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. For further information: <http://www.ipcc.ch>.

scientists from all over the world contribute to the work of the IPCC on a voluntary basis. Because of its scientific and intergovernmental nature, the IPCC embodies a unique opportunity to provide rigorous and balanced scientific information to decision makers. By endorsing the IPCC reports, governments acknowledge the authority of their scientific content. The work of the organization is therefore policy-relevant and yet policy-neutral, never policy-prescriptive.

The Fourth IPCC Assessment Report provided an integrated view of climate change and its introduction was able to bring science into popular consciousness (AR5 is now developing and it is programmed for 2013/2014).

In particular observed changes in climate and their effects on natural and human systems, regardless of their causes are summarized in Topic 1, in addition to the causes of the observed changes, in Topic 2. Topic 3 instead presents projections of future climate change and related impacts under different scenarios. Topic 4 discusses adaptation and mitigation options over the next few decades and their interactions with sustainable development while Topic 5 assesses the relationship between adaptation and mitigation on a more conceptual basis and takes a longer-term perspective. Finally Topic 6 presents the major robust findings and remaining key uncertainties in this assessment.

All climate information reported in IPCC work refer on a "uncertainty guidance note"<sup>4</sup> that specifies the degree of uncertainty and different used approaches for any given information.

From IPCC observations about Climate Change some important issues emerge as consolidated empirical evidence.

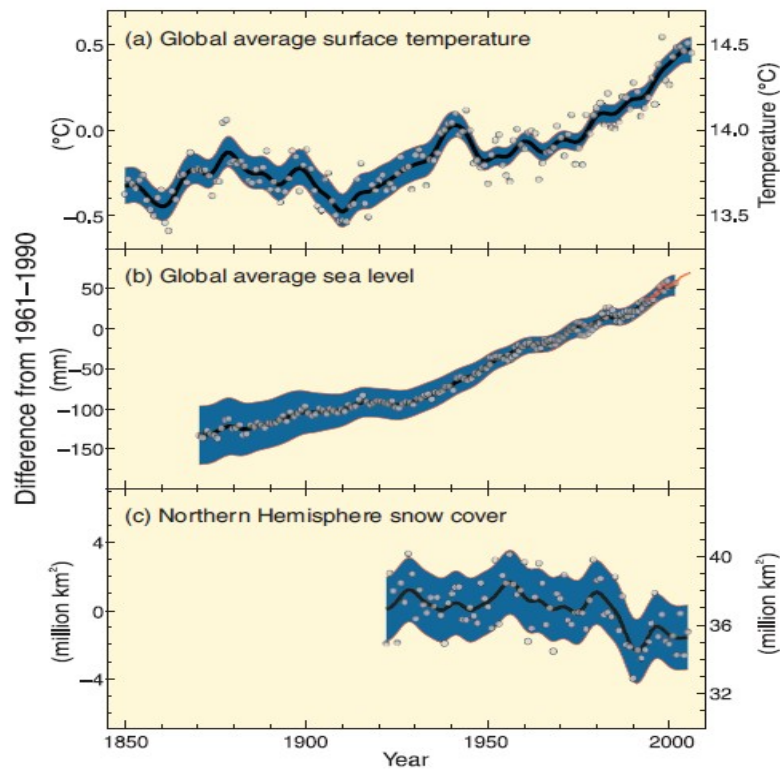
Warming of the climate system is to date well established. It is unequivocal, as it is evident from increases in global average air and ocean temperatures, in addition to the widespread melting of snow and ice and rising global average sea level (Figure 1). Other

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4 References: see "treatment of uncertainty" in IPCC Synthesis Report, p. 27.

observational evidence from continents around the world and most of the oceans shows that many natural systems are being affected by regional climate changes, in particular due to temperature increases. There are also evident effects of regional climate changes on natural and human environments that are emerging now, although many of these are difficult to discern, due to adaptation and non-climatic drivers that interact with other physical and natural elements and might procure some distortions about empirical findings (Figure 2).

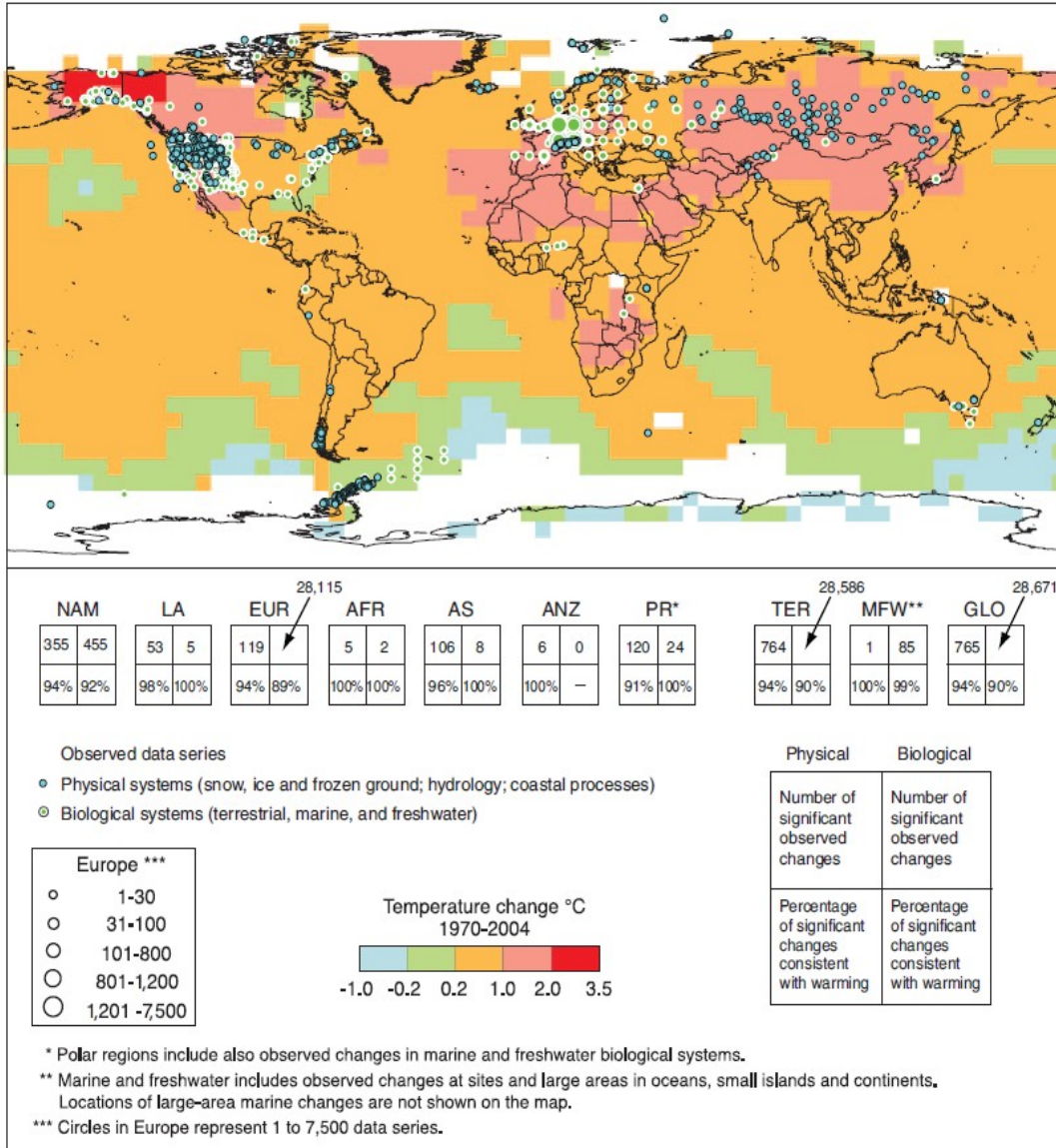
***Changes in temperature, sea level and Northern Hemisphere snow cover***



**Figure 1** presents observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values

while circles show yearly values. Source: IPCC AR4 SYR, p. 31.

**Changes in physical and biological systems and surface temperature 1970 – 2004**



**Figure 2** shows locations of significant changes in data series of physical and biological systems and surface air temperature over the period 1970 – 2004. The white areas on figure 2 don't provide sufficient datasets for calculate changes in temperature. The boxes

*show the number of data series with significant changes (top row) and the percentage of this changes consistent with temperature's increase (bottom row) for (a) regional-scale: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (b) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). Source: IPCC AR4 SYR, p. 32.*

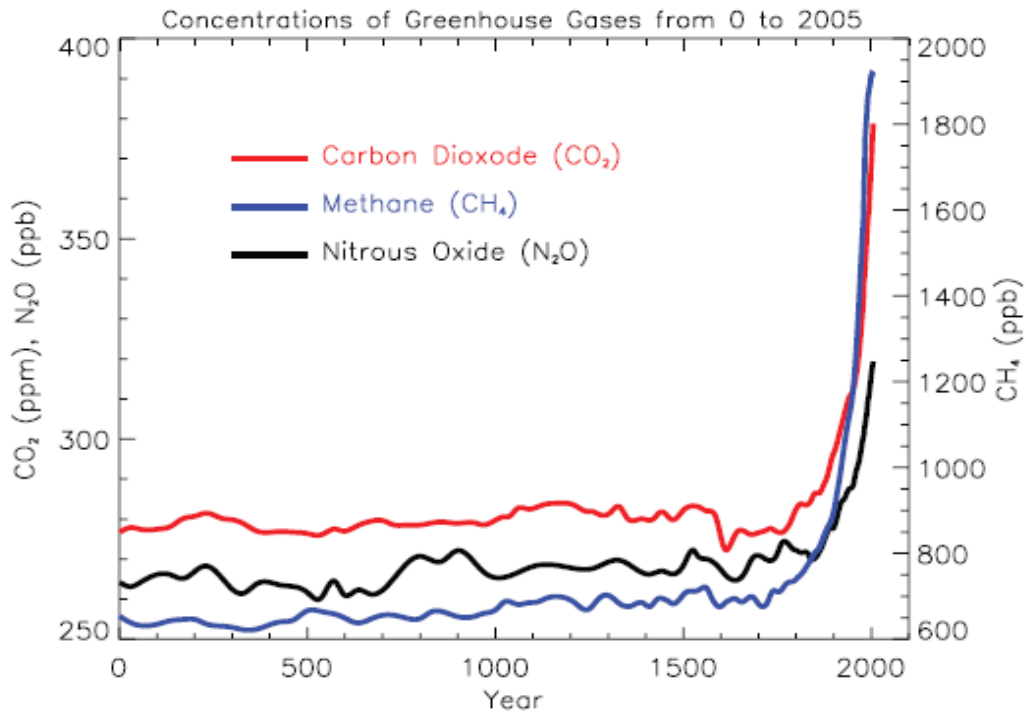
About the observations made by IPCC, involving natural and human factors that could cause climate change, the following evidences are provided, even if a certain degree of uncertainty is always take into account.

At this purpose, historically global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. GHG emissions and the related global warming problem represent probably the main factor in which studies are involved since the problem of climate change entered into societal consciousness.

Global atmospheric concentrations of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The atmospheric concentrations of CO<sub>2</sub> and CH<sub>4</sub> in 2005 exceed by far the natural range over the last 650,000 years (Figure 3). Several researches show that global increases in CO<sub>2</sub> concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in CH<sub>4</sub> concentration is predominantly due to agriculture and fossil fuel use, while the increase in N<sub>2</sub>O concentration is primarily due to agriculture.

IPCC assigns very high confidence to the fact that the global average net effect of human activities since 1750 has been one of warming.

### Concentrations of GHG until 2005



**Figure 3** shows the patterns followed by the three main component of GHGs, from 0 to 2005. Increases from 1750 are attributed to human activities in the industrial era.

Concentrations are part per million (ppm) or part per billion (ppb).

Source: IPCC, AR4, WG1, chapter 2, p. 135.

Since the TAR concluded that most of the observed warming over the last 50 years is likely to have been due to the increase in GHG concentrations, the advances occurred in next researches until our days, consolidate this tool, affirming these evidences are very likely. In fact it is extremely unlikely to explain global climate change of the past 50 years without external forcing, and very likely that it is not due to known natural causes alone.

Concluding the evidences related to climate warming, it is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica). This is also likely that this anthropogenic warming over the last three

decades has had a discernible influence on many natural systems.

Even if the given evidences are quite consolidated, some difficulties remain in simulating and attributing observed temperature changes at smaller scales. On these levels, natural climate variability is relatively larger, making it harder to distinguish changes expected due to external forcing. Uncertainties in local forcing, such as those due to aerosols and land-use change, and feedbacks also make it difficult to estimate the contribution of GHG increases to observed small-scale temperature changes.

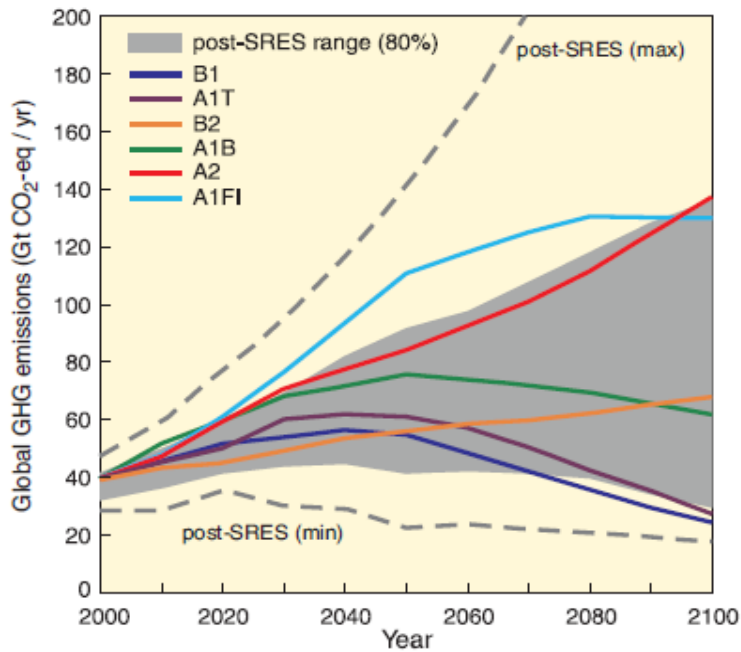
A synthesis of studies strongly demonstrates that the spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many natural systems consistent with warming is very unlikely to be due solely to natural variability of temperatures or natural variability of the systems. Several modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming, but only a few such studies have been performed.

### *1.1.2 Projections for Future Climate Change*

After have cited the empirical evidences about actual climate change, we now focus our attention on future climate change possible development. At this purpose, the third part of IPCC AR4 document provides climate change impacts in the near and long term under different scenarios. The findings deriving by Working Groups' studies, give the results reported as follows.

There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global GHG emissions are destined to grow over the next few decades. Baseline emissions scenarios published since the IPCC Special Report on Emissions Scenarios (SRES, 2000) are comparable in range to those presented in SRES (Figure 4 and the following box "SRES SCENARIOS").

**Scenarios for GHG emissions from 2000 to 2100 without climate policies**



**Figure 4** Global GHG emissions (in GtCO<sub>2</sub>-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and F-gases.

Source: IPCC AR4 SYR, p. 44.



**SRES SCENARIOS** refers to the scenarios described in the IPCC Special Report on Emissions Scenarios (SRES, 2000). Four scenario families are included (A1, A2, B1, B2) that refers to alternative development pathways based on different demographic, technological and economic driving forces and relative GHG emissions.

A1 storyline is characterized by a very rapid economic growth, a global population that peaks in mid-century and the introduction of new and more efficient technologies. Three different options differentiated by the technologies adopted are: A1FI (fossil intensive), A1T (non-fossil energy resources), A1B (balance across all sources).

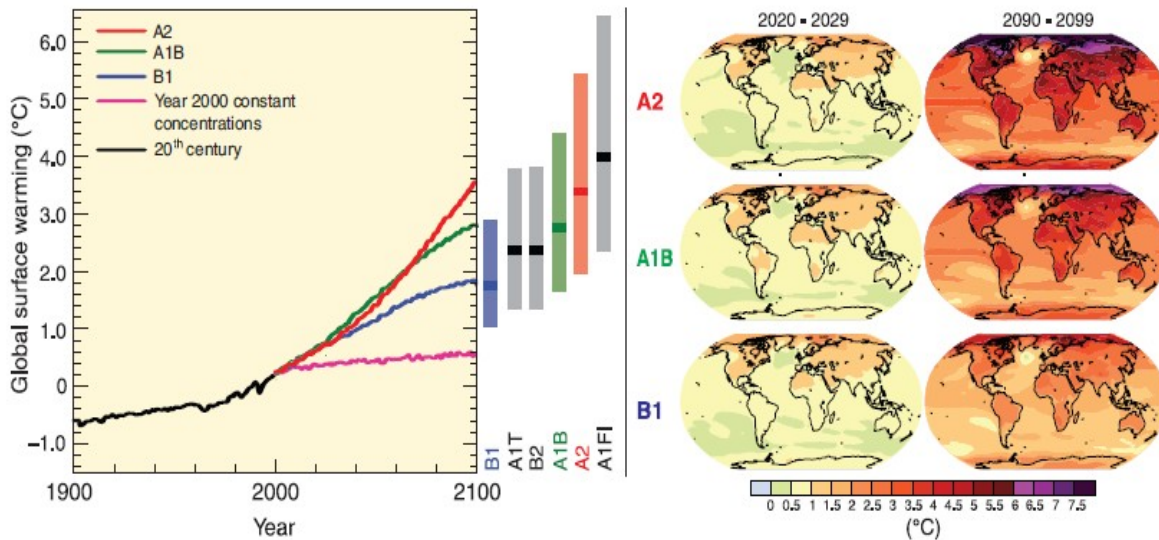
B1 scenario assumes a convergent world with the same population as A1 but with more rapid changes in economic structure toward a service and information economy.

B2 represent a world with intermediate population and growth, emphasizing local solutions to economic, social and environmental sustainability.

A2 describes a very heterogeneous reality, with high population growth, low economic progress and slow changes in technology.

For a range that is established by IPCC scenarios, a warming of about 0.2°C per decade is projected for the next two decades. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Moreover, temperature projections strictly depend on specific emissions scenarios, with the evident differences showed in Figure 5.

### Atmosphere-Ocean General Circulation Model projections of surface warming



**Figure 5** illustrates multi-model global averages surface warming (period 1980 – 1999) for the SRES scenarios that are indicated, as continuation of the 20<sup>th</sup> century simulations. In the middle of the figure are presented the best estimate and the likely range assessed for the six scenarios at 2090 – 2099 based on period 1980 – 1999. On the right side the figure shows projected surfaces temperatures for the early and late 21<sup>st</sup> century relatively the same period (1980 – 1999) for the three scenarios indicated. Source: IPCC AR4 SYR, p. 46.

It is expected that continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger compared to those observed during the 20th century.

The projected patterns regarding warming and other regional-scales features like changes in wind patterns, precipitation and some aspects of extremes and sea ice, is now higher confidence than in the TAR.

In addition, future anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilized.

A wide range of systems and sectors concerning the nature of future impacts provides to date a more specific information, also including some fields not covered in third assessments of IPCC. There are several studies applied since the TAR, that have enabled a more systematic understanding of the timing and magnitude of impacts relate to differing amounts and rates of climate change.

Through this researches, it was shown that some systems, sectors and regions are likely to be especially affected by climate change, while others are less influenced. This fact would continue in the next years, affecting the global system by imbalances that could cause an even more complex management of climate change.

Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems in the next future, as show by the IPCC following table (Table 1).

Finally, it is very important to notice the fact that anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change.

**Table 1** gives some examples of possible impacts of future climate changes due to climate variability and extremes events, based on mid/late 21<sup>st</sup> century projections. No changes or developments in adaptive capacity are taken into account. Source: IPCC AR4 SYR, p. 53.

Phenomenon <sup>a</sup> and direction of trend	Likelihood of future trends based on projections for 21 <sup>st</sup> century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems [WGII 4.4, 5.4]	Water resources [WGII 3.4]	Human health [WGII 8.2, 8.4]	Industry, settlement and society [WGII 7.4]
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	<i>Virtually certain</i> <sup>b</sup>	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	<i>Very likely</i>	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	<i>Very likely</i>	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	<i>Likely</i>	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	<i>Likely</i>	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis) <sup>c</sup>	<i>Likely</i> <sup>d</sup>	Salinisation of irrigation water, estuaries and fresh-water systems	Decreased fresh-water availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Notes:

a) See WGI Table 3.7 for further details regarding definitions.

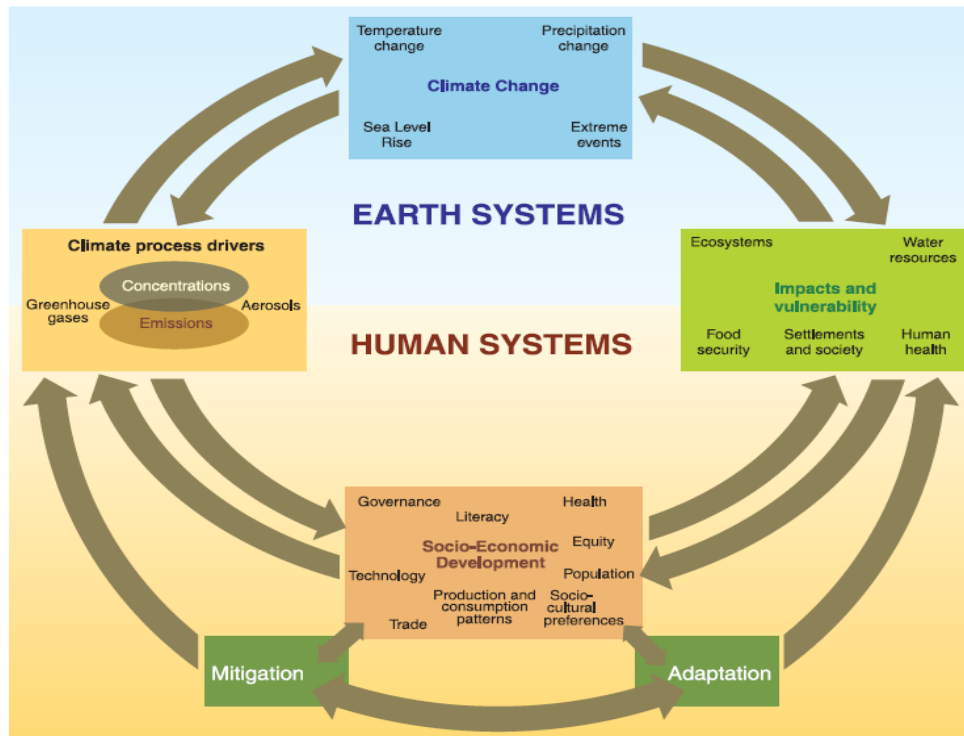
b) Warming of the most extreme days and nights each year.

c) Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.

d) In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed. [WGI 10.6]

## 1.2 Climate Change Impact on Socio-Ecosystem

The evidences expressed on the basis of IPCC AR4 documents, confirm there is an increasing awareness that climate change dynamics affect the related socio-ecosystem. It is well established that these impacts have to be considered not only in terms of weather change and conditions, but also referring to many socio-economic relapses. That consideration properly represent the notion of “socio-ecological systems” or “socio-ecosystems” (SEs), involving specifically the endogenous feedback between socio-economic and biophysical processes; these are defined as complex and adaptive systems (CASs) where social and ecological agents interact at multiple temporal and spatial scales. The picture below summarizes typical interactions; in particular anthropogenic climate change drivers, impact and responses and their linkages are highlighted.



**Figure 6** represents interactions between earth and human systems due to climate change. Source: IPCC AR4 SYR, p. 26.

Socio-ecological systems are based on the characteristics of Complex Adaptive Systems (CAS) represented by self-organization and co-evolutionary dynamics, with the presence of large macroscopic patterns which emerge out of local, small-scale interactions among system components (or agents) and the environment, these peculiarities often characterize systems involved by processes of path dependence and system memory. Through interacting with and learning from its environment, CASs are such type of systems that can modify their behaviour to adapt to changes in the relatives contexts. The results of these considerations are hierarchical aggregations in form of dispersed cross-scale interactions and processes of creating novelty, selection and adaptation in a context where inevitable uncertainty is always present.

In synthesis, the overall behaviour of the system is the result of a large number of decisions made by many individual and agents in different spatial and temporal scale. Climate and ecosystems are strongly interactive; changes at the regional to global scale can be amplified or modified by local processes, with significant consequences on socio-ecosystem functioning.

It is important to highlight again that systems we are treating are complex systems, so they are often characterized by non-linearity; in this sense, all SESs exist and function at multiple scales of space, time and social organization, and the interactions across scales are crucially important in determining the dynamics of the system at any particular focal scale. This interacting set of hierarchically structured scales is known as literature language as “Panarchy”; in few words, no system can be understood or managed by focusing on it at a single scale.

In this context, a key role is played by the “Resilience” of a socio-ecosystem, measured by the capacity of a system to absorb disturbance and reorganize itself while change occurs, so as to still retain essentially the same function, structure and feedback and therefore the same identity. In climate change field as in other sector and activities affected by

environmental variables, it would be fundamental to build up resilience as a strategy preventing the system from moving into an undesirable regime from which it is either difficult or impossible to recover. Resilience strategy could be seen in two different ways: to keep the system adequate compared to a particular configuration of the same (system regime) so that it will continue to deliver desired existing ecosystem goods and services, otherwise to move from a less desirable to a more desirable regime, adapting the characteristics of the system to an other configuration.

Having said that, in the specific context of complexity we are concerning, societies have two different ways of responding to climate change: the first one is adaptation, while the other one is mitigation option, by reducing GHGs emissions.

The capacity to adapt and mitigate depends on socio-economic and environmental circumstances and the availability of information and technology involved. However, as IPCC affirms, much less information is available about costs and the effectiveness of adaptation measures than about mitigation measures.

Specifically, in this thesis we will treat adaptation phenomena, by exploring how climate information could support decision-making in adapting to climate change into socio-ecosystems.

## **CHAPTER 2**

### **ADAPTATION: POSSIBLE SOLUTION OR NECESSARY DEVELOPMENT?**

Climate change adaptation is to date an urgent priority, thus for the custodians of national and local economies, such as finance ministers and mayors. Facing this problem, the typical decision-maker might ask: “what is the potential climate-related loss to our economies and societies over the coming decades?”; “how much of that loss can we avert, with what measures?”; “what investment will be required to fund those measures and will the benefits of that investment outweigh the costs?”

Past and the more recent literature tries to answer these typical questions by exploring behaviours concerning adaptation solutions and relative climatic features.

Using the term adaptation, we mean “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation”<sup>5</sup>.

Lord Nicolas Stern<sup>6</sup>, in UNEP report of the Economics of Climate Adaptation Working Group, describes climate change adaptation as essentially development in a hostile climate, based on the thought that, if people are well educated, have access to good basic services and can fall back on effective response systems in times of crisis they will be much less vulnerable to climate change.

In this chapter we will treat adaptation in specific. The first paragraph is largely based on IPCC AR4 WG2 considerations concerning the notion and the “state of the art” about the matter; in the second paragraph, a framework for decision-makers will be proposed, in according to the UNEP report of the Economics of Climate Adaptation Working Group,

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5 Source: IPCC AR4 Appendix I: Glossary. <http://www.ipcc.ch/pdf/glossary/ar4-wg2.pdf> .

6 Chair at Grantham Research Institute on Climate Change and the Environment, London School of Economics.



that regards a possible way to approach adaptation problem in decision-making processes.

### ***2.1 Through Adaptation Assessment***

Adaptation plays a crucial role in the field of climate change management because it is able to reduce the vulnerability<sup>7</sup> of a socio-ecosystem both in the short and in the long term. Nevertheless in the long run adaptation alone is not the unique solution to manage climate change problems.

Mainly we have three different type of adaptation. “Anticipatory adaptation” is also known as proactive adaptation, and takes place before impacts deriving from climate change are observed; “autonomous adaptation” could also be called spontaneous adaptation, not constituting a conscious response to climate change, but taking place through ecological changes in environmental field, and in market or welfare changes in human systems. This two types of adaptation, the way in which are carried an how they change over time will constitute the central point in analytical studies, also for which we will present in the fifth chapter of this thesis.

The third type of adaptation is called “planned adaptation”, resulting from a deliberate policy decision, based on the idea that climate conditions have changed or could change in the near future, so that actions are required to be adapted to these changes. Intergovernmental Panel on Climate Change provides an example of planned adaptation solutions by sector (Table 2).

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7 Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

**Table 2** shows possible adaptation options by sectors. Source: IPCC AR4 SYR, p. 57.

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; italics = opportunities)
<b>Water</b> (WGII 5.5, 16.4; Tables 3.5, 11.6,17.1)	Expanded rainwater harvesting; water storage and conservation techniques; water reuse; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; <i>integrated water resources management; synergies with other sectors</i>
<b>Agriculture</b> (WGII 10.5, 13.5; Table 10.8)	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological and financial constraints; access to new varieties; markets; <i>longer growing season in higher latitudes; revenues from 'new' products</i>
<b>Infrastructure/ settlement (including coastal zones)</b> (WGII 3.6, 11.4; Tables 6.11, 17.1)	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land-use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; <i>integrated policies and management; synergies with sustainable development goals</i>
<b>Human health</b> (WGII 14.5, Table 10.8)	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognise climate risk; strengthen health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; <i>upgraded health services; improved quality of life</i>
<b>Tourism</b> (WGII 12.5, 15.5, 17.5; Table 17.1)	Diversification of tourism attractions and revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives, e.g. subsidies and tax credits	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); <i>revenues from 'new' attractions; involvement of wider group of stakeholders</i>
<b>Transport</b> (WGII 7.6, 17.2)	Realignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial and technological barriers; availability of less vulnerable routes; <i>improved technologies and integration with key sectors (e.g. energy)</i>
<b>Energy</b> (WGII 7.4, 16.2)	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; <i>stimulation of new technologies; use of local resources</i>

From the studies constituting the Fourth Report on Climate Change, the Intergovernmental Panel on Climate Change affirms there is high confidence that many of the solutions presented in Table 2 could be implemented at positive benefits-costs ratios; this thought confirms adaptation is considered, in the cited sectors, a good solution for decision-makers to fight against climate change problem.

We now focus our attention on the “Assessment of adaptation practices, options, constraint and capacity” that constitute the 17<sup>th</sup> chapter of IPCC Working Group 2 contribute<sup>8</sup>. In that manner we aim to analyse in depth adaptation “state of the art” and its characters.

Although adaptation is considered vital and beneficial, it is equally true that societies with even high adaptive capacity<sup>9</sup> remain vulnerable to climate change, variability and extremes; in fact, as suggested by IPCC researches, the capacity to adapt is dynamic and is influenced by a society’s productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology; in few words it is affected by multiple climate and non-climate stresses, as well as development policy. We are not able to understand adaptation in its totality if we don't consider jointly all the cited factors that contribute to form adaptation actions.

To date, significant advances in adaptation assessment have occurred, gradually changing in particular from the focus in a research-driven activity to one where stakeholders

8 The literature studies cited in the next pages are taken from the 17<sup>th</sup> chapter of the Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 976 pp, [http://www.ipcc.ch/publications\\_and\\_data/publications\\_ipcc\\_fourth\\_assessment\\_report\\_wg2\\_report\\_impacts\\_adaptation\\_and\\_vulnerability.htm](http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm)

9 Adaptive Capacity reflects the ability of a system to change in a way that makes it better equipped to deal with external influences. It is function of Social Capacity (ability to predict and plan in a way to recover after being subject to threat or pressure) and Resilience.

participate in order to improve decision-making. The key advance in making this shift is represented by the incorporation of adaptation to past and present climate, giving the opportunity to anchor the assessment in what is already known and what can be used to explore adaptation to climate variability and extremes, especially in a situation where the scenarios of future variability are uncertain or unavailable.

In particular, since the Third Assessment Report, improvements in studying adaptation problem can be identified in: a) actual adaptations to observed climate changes and variability; b) planned adaptations to climate change in infrastructure design, coastal zone management, and other socio-economic activities; c) the variable nature of vulnerability and adaptive capacity; d) policy developments, under the United Nations Framework Convention on Climate Change (UNFCCC) and other international, national and local initiatives, that facilitate adaptation processes and action programs.

From the studies we are now referring, it is evident that adaptation measures can be differentiated along several dimensions. In this sense we have different practices in according to: spatial scale (local, regional, national); sector (water resources, agriculture, tourism, public health, and so on); type of action (physical, technological, investment, regulatory, market); actor (national or local government, international donors, private sector, NGOs, local communities and individuals); climatic zone (dryland, floodplains, mountains, Arctic, and so on); baseline income/development level of the systems involved (least-developed countries, middle-income countries, and developed countries); or some combination of these and other categories.

Furthermore, in relation to different temporal scale, adaptation can be view as a reaction to: current variability (which also reflect learning from past adaptations to historical climates); observed medium and long-term trends in climate and anticipatory planning in response to model-based scenarios developed on the basis of long-term climate change. These response levels are often intertwined, because of the interdependency between the considered processes, so indeed might be considered as a continuum.

There is a long record of practices to adapt to the impacts either of weather as well as natural climate variability on seasonal to inter-annual time-scales. The relative adaptation measures are proactive and reactive too, but the first type are probably those that currently have the greatest implications, as well as being those which have improved the most in the recent years, for example through the development of operational capability to forecast several months in advance the onset of El Niño and La Niña events related to ENSO<sup>10</sup>, as well as improvements in climate monitoring and remote sensing to provide better early warnings on complex climate-related hazards.

Since the middle 1990s, a number of mechanisms have also been established to facilitate proactive adaptation to seasonal to decadal climate variability. These include institutions that generate and disseminate regular seasonal climate forecasts, like for example NOAA, and the regular regional and national forums and implementation projects worldwide to engage with local and national decision makers to design and implement anticipatory adaptation measures in agriculture, water resource management, food security, and a number of other sectors.

Researches based on 1997-98 El Niño regarding some developing countries revealed a number of barriers to effective adaptation, including spatial and temporal uncertainties associated with forecasts of regional climate, low level of awareness among decision makers of the local and regional impacts of El Niño, limited national capacities in climate monitoring and forecasting, and lack of co-ordination in the formulation of responses. Recent studies also point out that technological solutions such as seasonal forecasting are not sufficient to address the underlying social drivers of vulnerabilities to climate.

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10 From WMO: ENSO stands for El Niño/ Southern Oscillation. The ENSO cycle refers to the year-to-year variations in sea- surface temperatures, convective rainfall, surface air pressure, and atmospheric circulation that occur across the equatorial Pacific Ocean. El Niño refers to the above-average sea-surface temperatures that periodically develop across the east-central equatorial Pacific. It represents the warm phase of the ENSO cycle. La Niña refers to the periodic cooling of sea-surface temperatures across the east-central equatorial Pacific. It represents the cold phase of the ENSO cycle; [http://www.wmo.int/pages/mediacentre/press\\_releases/pr\\_925\\_en.html#back](http://www.wmo.int/pages/mediacentre/press_releases/pr_925_en.html#back)

Furthermore, social inequities conditioning the access to climate information and the lack of resources to respond can severely affect proactive adaptation.

Several studies implemented adaptation measures involving directly climate prediction from observed medium- to long-term trends in climate, as well as using scenarios for future climate change patterns. Also public health adaptation measures have been put in place, that combine weather monitoring, early warning, and response measures in a number of places including metropolitan cities. Weather and climate extremes have also suggested a number of adaptation responses in the financial sector by the use of specific insurance measures regarding sensitive activities to climate variability.

To date, there are growing adaptation measures putted in place to take into account scenarios of future climate change and associated impacts relatively to durable infrastructures exposed to climate risk, in addition to other several examples of climate change strategies integrated with risk management at local, regional and national scale.

About the quantification of adaptation's costs and benefits, generally costs are expressed by monetary value instead benefits could be monetary or non-monetary values; anyway the literature about remains quite limited and fragmented.

Researches mentioned by International Panel on Climate Change WG2 concerning assessment of adaptation costs and benefits are mainly focused on sea-level rise and agriculture. In the field of sea-level rise the emergent results agree that adaptation measures are largely successful and costs don't affect very much the GDP in considered countries, so it seems to be clear the benefit given by adaptation. On the contrary one limit of this studies resides in the fact that topics such as the implications of extreme events generally are not considered. A second limitation of sea-level rise costing studies is their sensitivity to (land and structural) endowment values which are highly uncertain at more aggregate levels. These two considerations clearly condition the results, augmenting their rate of uncertainty.

About agricultural sector the literature largely report to adaptation benefits. Costs are not considered in early studies but are usually included in recent ones. The results show that adaptation measures in this sector can improve a lot cultures average yields and could also smooth out fluctuations in yields (and consequently social welfare) as a result of climate variability. In this field there are limitations given by the diversity of climate change impacts and adaptation options and the complexity of the adaptation process. Even if agricultural regions can adapt fully through technologies and management practices, there are likely to be costs of adapting the process in a way to adjust it to a new climate regime. Given so, the studies that consider perfect adaptation by individual farmers without considering any implication in terms of cost, are probably based on unrealistic assumptions.

In terms of regional coverage, there has been a focus on the United States and other OECD countries, although there is now a growing literature for developing countries also. In estimates of global impacts of climate change, researches affirm that between 7% and 25% of total climate damage costs included in earlier studies could be classified as adaptation costs. However, it is important to note that these studies offer a global and integrated perspective but are based on coarse definitions about climate change and adaptation impacts, so that they can only provide speculative estimates of adaptation costs and benefits. So, in this totality, IPCC affirms that current literature does not provide comprehensive multi-sectoral estimates of global adaptation costs and benefits. The broader macroeconomic and economy-wide implications remain largely unknown.

As we have already mentioned in the beginning of this chapter, adaptive capacity play a crucial role in climate change impacts assessment. With this term we refer to the ability or potential of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope

with the consequences<sup>11</sup>.

Many studies deal with adaptive capacity defining it as a necessary condition for the design and implementation of effective adaptation strategies so as to reduce the impacts resulting from climate change.

Much of the understanding about adaptive capacity is linked to vulnerability assessment, often providing important insights on the factors, processes and structures that can promote or constrain adaptive capacity. One important consideration resulting from these studies is that some dimension of adaptive capacity can be defined as generic while others dimensions are fully connected to particular climate change impacts. For example although technological capacity can be considered a key aspect of adaptive capacity, many technological responses to climate change are closely associated with a specific type of impact, such as higher temperatures or decreased rainfall.

Studies developed since the TAR show that adaptive capacity is influenced by economic development and technology as well as by social factors such as human capital and governance policies.

It is quite evident that the capacity to adapt is unequal across and within societies and there are specific contextual factors that shape vulnerability and adaptive capacity, influencing how they may evolve over time. At this purpose new researches focus their attention on the conditions that constrain or enhance adaptive capacity at the continental, regional or local scales. These studies show some peculiarities, in particular mentioning the influence that some social components have into adaptive capacity properties; the nature of the relationships between community members is critical, as is access to and participation in decision-making processes. In addition is also shown how adaptive capacity is also highly heterogeneous within a society or locality, and human populations differing by age, class, gender, health and social status.

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11 Definition of adaptive capacity taken from IPCC AR4 Appendix I: Glossary. <http://www.ipcc.ch/pdf/glossary/ar4-wg2.pdf>.



Furthermore at any scale or system we consider there are agents outside the specific field of research that affect adaptive capacity. We refer for example to policy measures applied at local scale that can limit agents' behaviour to act and react through adaptation. Some studies explore how vulnerability and adaptive capacity are influenced by multiple process of change in society such as urbanization or trade liberalization, as two of the possible implication regarding policy constraints. Others, instead, show how actions in one region could create vulnerability in the other through direct or indirect interactions, a sort of cross-side effect within regions.

In summary, empirical researches carried out since the TAR have shown that simple cause-effect relationships between climate change risks and the capacity to adapt are very rare, while an integrated view of the problem is suggested, or better is due, to well understand system capability to face climate change through adaptation.

Adaptive capacity often vary over time and it's affected by multiple processes of change. In general, the emerging literature shows that the distribution of adaptive capacity within and across societies represents a major challenge for development and a major constraint to the effectiveness of any adaptation strategy.

To complete the "state of the art" about adaptation, a recent literature has to be mentioned, focuses on the importance of social policy in facilitating adaptation to climate change. These actions could take place by reducing vulnerability of people and infrastructure, providing useful information and protecting public goods like environment. Improvement have been made also by UNFCCC, in particular providing developing countries by NAPAs programs (National Adaptation Programmes of Action), in this manner facilitating several adaptation plans. In completing this program a country defines its priorities and actions to implement for facing urgent national climate change adaptation needs.

Much of the adaptation planning literature emphasizes the role of governments in

facilitating adaptation practices, but also mentions that governments could be a constraint for these types of actions as well as an important vehicle for their implementation. Some studies cited by IPCC WG2 in the 17<sup>th</sup> chapter involving adaptation identify five major constraints that limit the effect of governmental actions. The relevance of climate information for development-related decisions; the uncertainty of this type of information; the compartment division with governments; the segmentation and other barriers within development-cooperation agencies and finally the trade-offs between climate and development objectives often conflicting.

To try to overcome these barriers, the United Nations Development Programme developed the Adaptation Policy Framework (APF) that aims to help countries as they integrate adaptation concerns into the broader goals of national development. The development of the APF was motivated because the rapidly evolving process of adaptation policy making has lacked a clear roadmap, so that APF is proposed as the guidance framework. It try to offer a flexible approach through which users can clarify their own priority issues and subsequently implement responsive adaptation strategies, policies and measures.

However APF, even if considered a possible solution, it is not approved by the totality of the entities and agents involved in adaptation to climate change study, for example because of some problems related to local socio-economic information and in stakeholder participation in the adaptation projects, that make also this application feasible in some cases.

Summarizing, the great importance of adaptation practices is consolidate by past and modern literature too. But is also evident that adaptation has limits, some posed by the magnitude and rate of climate change; others related to financial, institutional, technological, cultural and cognitive barriers; the implementation of adaptation into governmental planning depends on how we are able to overcome these barriers and

limits. Policy and planning processes need to take these aspects into account in the design and implementation of adaptation and these considerations also suggest that a high priority should be given to increasing the capacity of countries, regions, communities and social groups to adapt to climate change in ways that are synergistic with wider societal goals of sustainable development.

## ***2.2 Possible Frameworks for Adaptation Options***

The considerations on adaptation actions we have already tell about involve many problems relative to different kind of measures and the way decision-makers can choose and manage them.

IPCC WG2, in its contribution to adaptation to climate change<sup>12</sup>, proposes some frameworks for Climate Change Impacts, Adaptation and Vulnerability assessment (CCIAV) focusing on the methods available in that analysis and how to manage the associated uncertainty.

The basic approach to develop CCIAV assessment has been the climate “scenario driven impact approach”, developed from the seven-step assessment framework of IPCC (1994), presenting, in synthesis, the following phases: 1. Define problem, 2. Select method, 3. Test method/sensitivity, 4. Select scenarios, 5. Assess biophysical/socio-economic impacts, 6. Assess autonomous adjustments, 7. Evaluate adaptation strategies. This method, described in previous IPCC reports, aims to evaluate the likely impacts of climate change under a given scenario and to assess the need for adaptation and/or mitigation to reduce any potential vulnerability deriving from climate risks. Other methods subsequently discussed by IPCC in the assessment of CCIAV were “adaptation-based”, “vulnerability

<sup>12</sup> References from chapter 2 of the Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 976 pp, [http://www.ipcc.ch/publications\\_and\\_data/publications\\_ipcc\\_fourth\\_assessment\\_report\\_wg2\\_report\\_impacts\\_adaptation\\_and\\_vulnerability.htm](http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm)

based” and “integrated approaches”; these methods are increasingly being incorporated into mainstream approaches to decision-making.

Always referring to these approaches, the adaptation-based focuses on risk management, in particular analysing the adaptive capacity and the adaptation measures required to improve the resilience or robustness of a system exposed to climate change. In contrast, the vulnerability-based approach focuses on the risks themselves, with the difference that it concerns the propensity to be harmed, then seeking to maximize potential benefits and minimize or reverse potential losses. However, these approaches are interrelated, especially with regard to adaptive capacity. Integrated approaches involve integrated assessment modelling and other procedures for investigating CCIAV across several disciplines, sectors and scales, by representing key interactions and feedback.

Table 3 resume the methods we have just tell about.

	Approach			
	Impact	Vulnerability	Adaptation	Integrated
<b>Scientific objectives</b>	Impacts and risks under future climate	Processes affecting vulnerability to climate change	Processes affecting adaptation and adaptive capacity	Interactions and feedbacks between multiple drivers and impacts
<b>Practical aims</b>	Actions to reduce risks	Actions to reduce vulnerability	Actions to improve adaptation	Global policy options and costs
<b>Research methods</b>	Standard approach to CCIAV Drivers-pressure-state-impact-response (DPSIR) methods Hazard-driven risk assessment	Vulnerability indicators and profiles Past and present climate risks Livelihood analysis Agent-based methods Narrative methods Risk perception including critical thresholds Development/sustainability policy performance Relationship of adaptive capacity to sustainable development		Integrated assessment modelling Cross-sectoral interactions Integration of climate with other drivers Stakeholder discussions Linking models across types and scales Combining assessment approaches/methods
<b>Spatial domains</b>	Top-down Global → Local		Bottom-up Local → Regional (macro-economic approaches are top-down)	Linking scales Commonly global/regional Often grid-based
<b>Scenario types</b>	Exploratory scenarios of climate and other factors (e.g., SRES) Normative scenarios (e.g., stabilisation)	Socio-economic conditions Scenarios or inverse methods	Baseline adaptation Adaptation analogues from history, other locations, other activities	Exploratory scenarios: exogenous and often endogenous (including feedbacks) Normative pathways
<b>Motivation</b>	Research-driven	Research-/stakeholder-driven	Stakeholder-/research-driven	Research-/stakeholder-driven

**Table 3** resumes the four methods in assessing CCIAV.

Source: IPCC AR4 WG2, Chapter 2, p. 137.

The United Nation Environmental Programme (UNEP) too, tries to provide decision-makers with a systematic way of answering specific questions related to “adaptation and climate change”, focusing in specific on the economic side of adaptation and delineating a fact-based risk management approach that national and local leaders could use to understand the impact of climate on their economies and in that manner identifying actions to minimize the negative impacts at the lowest cost to their society.

The continuation of this paragraph refers to the cited UNEP report, based on the initial findings of a study by the “Economics of Climate Adaptation Working Group”, considering the contribution of “ClimateWorks Foundation”, “Global Environment Facility”, “European Commission”, “McKinsey & Company”, “The Rockefeller Foundation”, “Standard Chartered Bank” and “Swiss Re”<sup>13</sup>.

It is to date well established that, for the custodians of national and local economies it is a key challenge to understand what value, which people, assets and sectors are at risk, both from historic climate patterns and from the incremental threat of possible climate change. To manage this type of problems, decision-makers need a robust yet rapid way to identify the adaptation measures required in the near-term to limit as possible potential loss at the lowest possible cost to society. This is what the Adaptation Framework, developed by UNEP, aim to.

The Intergovernmental Panel on Climate Change (IPCC) has noted that many of the adaptation practices can be implemented at low cost, but also that comprehensive costs/benefits estimates in adaptation field are currently lacking. Indeed, extensive work has been done to identify effective adaptation measures, like for example the National Adaptation Programs of Action (NAPA), but to date no systematic approach were found to

<sup>13</sup> References: A report of the Economics of Climate Adaptation Working Group. Shaping Climate-Resilient Development: a framework for decision-making, ClimateWorks Foundation, Global Environment Facility, European Commission, McKinsey & Company, The Rockefeller Foundation, Standard Chartered Bank and SwissRe, 2009; [http://www.mckinseysociety.com/downloads/reports/Economic-Development/ECA\\_Shaping\\_Climate%20Resilient\\_Development.pdf](http://www.mckinseysociety.com/downloads/reports/Economic-Development/ECA_Shaping_Climate%20Resilient_Development.pdf).

calculate and compare the costs and economic benefits of these measures, using bottom-up estimates.

The Economics of Climate Adaptation Working Group tries to build out this knowledge base, in particular filling two specific gaps identified in existing studies, consisting in:

- the limits to the quantification of risk: consisting on the fact that there is no systematic way of estimating climate risk, and no general methodologies that can simplify comparisons between the risks posed by different hazards and in different geographies;
- the lack of decision support tools: as the existing researches and policy base does not provide overarching decision-making methodology to address climate risk in a systematic and resource-efficient way.

The framework is based on two core beliefs. First, a critical target for decision-makers is to address the total climate risk (both current and future); second, it is very important to remember that adaptation has major potential impacts on economics, so it is evident that decision-makers have to integrate climate adaptation with economic development, as to avoid to think about climate risk only as an environmental problem.

Consequently to this two principles the Working Group establishes five steps in managing the total climate risk of a region. The phases are the following:

1. Identify most relevant hazards and the regions and populations that are most at risk;
2. Calculate the expected loss by different climate scenarios to assess uncertainty;
3. Build a portfolio of responses with related costs-benefits analysis;
4. Implement a holistic climate risk strategy for the following adaptive initiatives;
5. Collect the results of this initiatives as successfully ones or as a mean to improve

future climate challenges.

The Working Group's efforts presented in the UNEP report were focused on applying this framework across some local test cases that involves developed and developing countries. The studies were based on broad metrics of climate-related economic loss, such as GDP, asset value, and agricultural production, and in most cases did not attempt to calculate the additional social and environmental costs of climate impacts.

In selected studies, however, the methodology included human costs, through an assessment of the health impacts of climate risk, and the losses facing particular economic sectors such as power generation.

All these cases follow the five steps mentioned above, starting from determine the most relevant local climate hazards and the area most at risk in the location under study. Subsequently it is necessary to quantify the expected loss for the area under study following a probabilistic loss model approach, for each of the three climate change scenarios included in the analysis: "today's climate", "moderate climate change", and "high climate change"; it is important to underline that this three scenarios do not derive from SRES scenarios we have already tell about analysing climate change through IPCC results. Once the potential loss is calculated the last phase regards the identification of a comprehensive set of potential climate resilience and adaptation measures that, in the cited researches, were identified by scanning existing literature, including academic and NGO<sup>14</sup> reports, and by interviewing local experts and government officers.

It is important to highlight that, many of the solutions we examine are developing measures, that have to be considered in a different way from adaptation measures. What makes adaptation different is the scale and the priority of measures selected. Scale, in the sense that the future climate risk is different from today's, and so the penetration rate of certain measures will be higher than it would be without the increased risk. Priority, as the

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14 Non-Governmental Organization.

measures that address climate risk cost-effectively will be more important than alternative development choices that do not. It is the quantitative understanding of risk that allows such trade-offs.

At the end of this procedure the Working Group examines societal effects of adaptation and provides a “cost curve” as the output of the analysis, describing a set of cost-effective measures around which a country can build its adaptation strategy (Figure 7).

**Adaptation “cost curve”**

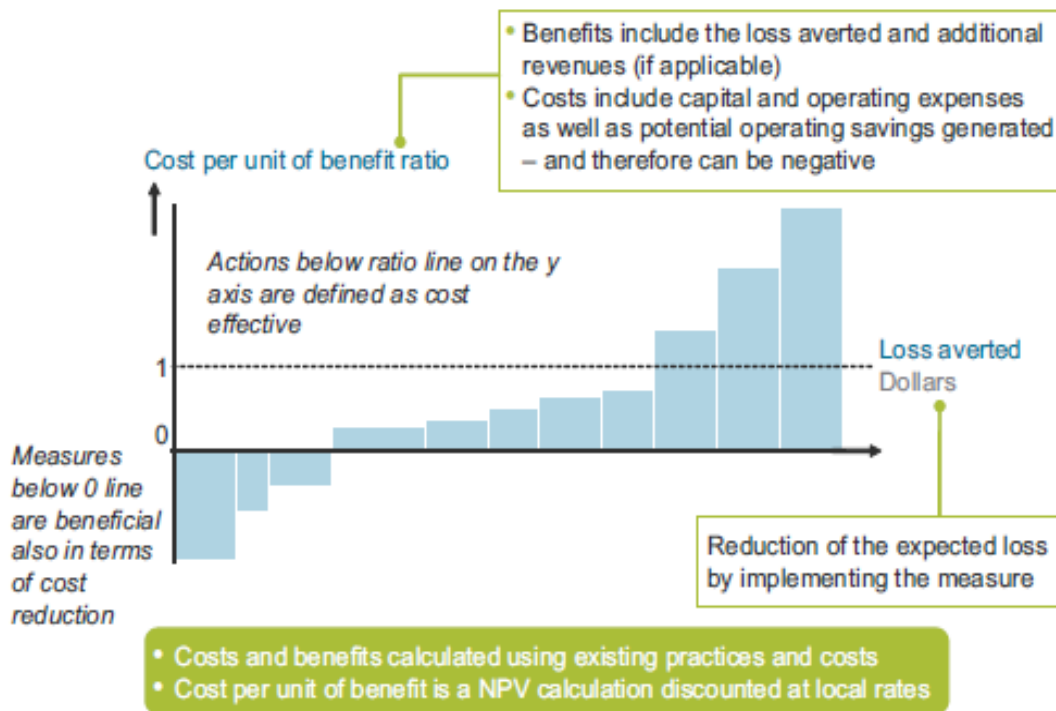


Figure 7 shows adaptation measures disposed by its cost-effectiveness.

Source: UNEP, ECA Working Group, p. 32.

In Figure 7, each adaptation measure is plotted on the cost curve, ranging from the most cost-effective on the left of the curve, to the relatively least cost-effective on the right



side. The horizontal axis expresses the total extent of the loss averted by the measures, while the vertical axis indicates the cost per unit of benefit for each measure, accounting for the capital and operational expenditure required to put those measures in place.

Referring to this method, we can have three different cost-benefit solutions relative to different adaptation options:

- Measures that are cost-negative, and that therefore create savings;
- Measures with a cost-benefit ratio below 1, that are measures whose economic benefits outweigh their costs;
- Measures with a cost-benefit ratio above 1, namely cost-inefficient measures.

It is important to specify that, the measures standing on the left side of the curve are not absolutely the best adaptation measures. The curve is a base indicator, and a broader set of selection criteria, covering both evaluation and implementation of the methodology involved, will be required, including also measures' potential for impact, their ease of execution, their synergies, as well as their coverage compared to different frequencies of hazards.

Given so, we have to remember that this risk evaluation strategy concerns only discrete adaptation options, rather than the full spectrum; it must be suitably modified to take into account synergies or dis-synergies between different measures. In summary, it represent a static and consequently a limited view.

It is however interesting to mention the results carried out by test cases explored in the UNEP framework, in such a way to understand how different countries can react to adaptation actions and policies. Although these findings do not constitute full answers to the adaptation challenges, they provide a useful indication<sup>15</sup>.

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15 For further information about all the test cases involved in the UNEP analysis:

[http://www.mckinseysociety.com/downloads/reports/Economic-Development/ECA\\_Shaping\\_Climate%20Resilient\\_Development.pdf](http://www.mckinseysociety.com/downloads/reports/Economic-Development/ECA_Shaping_Climate%20Resilient_Development.pdf)

In particular there are four findings that stand out from test cases taken in exam:

- With the own knowledge, nowadays modern societies and related governments and organizations are enough able to plan theoretical multiple scenarios related to climate change, and the relatives measures to face adaptation problems;
- It is quite prominent that climate change affect economic variables, such as GDP and other factors, and that significant economic values are at risk in the next years;
- In most cases projected loss can be averted with correct adaptation measures. Furthermore these measures many times are cost-negative, so societies could benefit two times.
- Very often the adaptation measures implemented can also boost economic development, for example improving infrastructures or optimizing some cultivation plans.

The findings deriving from the test cases presented in the UNEP report, could be generally adopted as indicators for the global situation.

In that way, even if a veil of uncertainty remains, as an intrinsic characteristic of the theme we are treating, it seems clear that adaptation measures to face climate change impact are not only possible, but in many times are also convenient in cost/benefit terms.

These evidences clearly express one more time the importance in assess climate change problems and manage them through appropriate adaptation policies, also as instrument for development.

However, in reality these measures are probably not considered at the same manner as their potentials, so that their effective utilization remain underutilized.

This inefficiency could derive in particular from two factor; the first one could be represented by governments' handling, that can limit in different way the implementation of important adaptation measures. On the other side, a real problem could derive from

difficulties in terms of information collection, dissemination and use, among the agents involved in the management of possible adaptation practices. In particular the problem linked to the management of the climate information assume a key role in this thesis, being the key input in any analysis related to climate change issue, in particular concerning adaptation challenge.

## **CHAPTER 3**

### **THE ROLE OF CLIMATE SERVICES AND INFORMATION THROUGH GFCS**

In the adaptation to climate change context, the importance of collection, dissemination and use of climate information is crucial. In general the term “climate information” includes historical data, analyses and assessments based on these data, forecasts, predictions, outlooks, advisories, warnings, model outputs, model data, climate projections and scenarios, climate monitoring products, etc., and can be in the form of text, maps, charts, trend analyses, graphs, tables, GIS<sup>16</sup> overlays, photographs, and satellite imagery, etc.

Adapting to climate change requires improvement in understanding of the linkages between climatic conditions and the outcomes of climate sensitive process or activities; nonetheless past empirical studies highlighted some limits to effective use of such information for economic benefits including: low accuracy and lack of lead time; institutional constraints relating to social aspects; lack of locational specificity of climate information and lack of knowledge about climate variability impacts and the associated decision responses (D. Gunasekera, 2010).

While the IPCC assessment of climate has raised political awareness about actual and future climate change problems, now the key challenges for climate information providers and users involve removing these impediments to ensure further facilitation of effective use of such information.

This aim could be achieved through “multidisciplinary approaches”, trying to make available regional and location specific user friendly climate information across a range of time and space resolutions for adaptation and climate risk management.

In this chapter, we will treat climate services with respect to the Global Framework for

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<sup>16</sup> Geographic Information System.

Climate Services (GFCS), provided by WMO<sup>17</sup>.

### ***3.1 The crucial importance of climate services and information and the fundamentals of the Global Framework for Climate Services***

Climate information is needed across a wide range of sectors; to discover synergies across these sectors and between agents and the relative socio-ecosystem dynamics it is necessary to go back to processes of social co-learning between information providers, decision-makers and the entire society. In the context of human-forced climate change vulnerability, risk assessment frameworks and strategic planning for adaptation have to be developed in such a way to coordinate the integration of climatic information with socio-economic information across sectors and jurisdictions. In this scenario, climate services play a fundamental role, being the main component in the described context of development, as the fundamental institutions that can allow the integration between providers and users of climatic information.

A key constraint established for the use of this type of information, concerning in particular future projections, is the respect of some essential characters like credibility, salience and relevance. As described in Munang et al. (2010), credibility can be built through effective partnerships and an understanding of the issue of uncertainty; salience means that information must be seen by stakeholders as relevant to their decision-making process. In this sense salience can be seriously compromised when information refers to geographic, temporal or organizational scales that do not match those of decision-makers. Addressing the issues improves the likelihood that appropriate climate information needs will be met, and increases the potential for viable ecosystem management solutions to be

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17 References: Global Framework for Climate Services, Concept Note, [http://www.wmo.int/pages/prog/wcp/ccl/documents/ConceptNote\\_GlobalFramework\\_ver3.4110309.pdf](http://www.wmo.int/pages/prog/wcp/ccl/documents/ConceptNote_GlobalFramework_ver3.4110309.pdf); Climate Knowledge for Action: a Global Framework for Climate Services – Empowering the Most Vulnerable, [http://www.wmo.int/hlt-gfcs/downloads/HLT\\_book\\_full.pdf](http://www.wmo.int/hlt-gfcs/downloads/HLT_book_full.pdf)

found.

However, even if the local context and characters are a key element in assessing which climate information are appropriate and which ones are misleading, common considerations (or decision criteria) such as responses to risk, threats, vulnerabilities and opportunities exists and can be used to structure a generic scheme within which basic principles can be applied to information provision. So, a core approach for information provision can be developed, around which individual solutions to specific issues can evolve (R. Munang, M. Rivington, E.S. Takle, B. Mackey, I. Thiaw and J. Liu, 2010).

The Global Framework for Climate Services (GFCS) document proposed a program that link climate predictions, projections and information with climate risk management and adaptation. In this sense, the framework aim to vehicular climate information in the right way among different users and functions.

From global to local levels, public and private sector institutions are seeking the tools and the knowledge to manage climate risk (Climate Risk Management, CRM)<sup>18</sup>. Consequently many of the world's leading development institutions are reviewing their programs following this perspective.

Similarly, national governments, and decision/policy makers at regional and local levels are undertaking the same actions, asking the question of how they can better manage climate related risks and opportunities.

To date, the most relevant information are available for societies, particularly at global scale; monitoring information from ground stations and satellites is usual, and global scale seasonal to inter-annual climate forecasts are produced at several centres. However, these knowledge and tools need to be adapted, improved and made available to optimize

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18 CRM is an approach to decision making in climate sensitive activities (e.g. agriculture and food security, health, tourism, management of water and energy resources, urban planning and design, transportation, etc.), that aim to reduce the vulnerability associated with climate risk (both variability and change), and to both maximize the positive and minimize the negative outcomes for these sectors.

the existing options for climate change adaptation, disaster risk reduction, development and sustainability. Integration of climate information into decision-making in various sectors of society allows more effective climate risk management strategies in support of the achievement of economic and development goals, including the Millennium Development Goals.

The provision of adequate and timely climate information and its appropriate use follow basically two targets: first to develop a system for production and delivery of climate information from global to local scales, and second to ensure an effective well understanding of the information by decision makers. In few words these aim can be viewed as the efficiency and the effectiveness related to climate information.

To meet this twin challenge WMO provided a Global Framework for Climate Services, that involves different character relative to climate information like observations, research, operational climate information generation, and user interaction mechanisms to improve the utility and content of the information. In this manner the aim is well established: to bridge the gap between providers and users of climate information.

We can define the core of GFCS mentioning four main components: Research; Observations; Service Provision and Service Application. The GFCS was developed in according to WCC-3 goals<sup>19</sup>, and has the aim to provide a cooperative framework for nations, as well as organizations, in a way to identify the needs of end-users. In addition it wanted to enable users to benefit from improved climate prediction and information services, trying also to improve climate science globally in a way to advance the skills of seasonal to inter-annual and multi-decadal climate predictions. An other target to be achieved consists of the ensure an ongoing assessment of the current state of knowledge

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<sup>19</sup> The World Climate Conference3 (WCC3), being organized by World Meteorological Organization in collaboration with other UN system agencies and partners, is designed to respond to the growing need of users and sectors worldwide to reduce the impacts of natural disasters, enhance food security and adapt to climate variability and change by engaging all provider and user groups in a collaborative process leading to the development and application of seasonal to multi-decadal climate predictions and products, among other climate and environmental information. Source: GFCS - Concept Note, p. 2.

and adaptive capacity across communities and the encourage of principles and mechanisms for sharing new advances in science and information through a cooperative global infrastructure system.

Following we briefly present WCC-3 outcomes<sup>20</sup>, also supported by Global Framework for Climate Services, consisting in:

- WCC-3 Goal 1: Improve data-gathering networks and information management systems for both climate and ecosystem sectors;
- WCC-3 Goal 2: Improve integration of regional and national infrastructure for the effective delivery through appropriate communication of climate information and predictions to national governments, agencies and the private sector;
- WCC-3 Goal 3: Strengthen scientific and technical capabilities to provide more credible and user-oriented climate information and predictions by reinforcing international, national and regional scientific mechanisms;
- WCC-3 Goal 4: Enhance the ability of governments, societies and institutions to access and use climate prediction and information.

The first two World Climate Conferences in 1979 and 1990 laid the pillars for building research and observational activities about understanding the nature of the climate challenges and to provide the scientific bases for developing comprehensive and sound climate services that are now being followed by all countries and in virtually every sector of society. The World Meteorological Organization and its partners established the third World Climate Conference to provide nations with the opportunity to jointly consider an appropriate global framework for climate services over the coming decades that would help ensure that every country and every climate-sensitive sector of society has

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<sup>20</sup> Source: Munang et al. 2010. For further details on WCC-3: Report of the World Climate Conference 3. [http://www.wmo.int/pages/gfcs/documents/wcc3\\_summary\\_report\\_web\\_EN.pdf](http://www.wmo.int/pages/gfcs/documents/wcc3_summary_report_web_EN.pdf)



consolidated instruments and tools to access and apply the growing array of climate prediction and information services, that recent and emerging developments in international climate science and technology make possible.

A wide cross-section of climate scientists, expert providers of climate information and the users of climate information and services concluded that available capabilities to provide effective climate services are still far from meeting the present and future needs and benefits, particularly in developing countries; the primary and probably most urgent need is the creation of a closer partnerships between the providers and users of climate services.

Great scientific progress has been made along time, especially by the “World Climate Programme” and its associated activities, which provides already a firm basis for the delivery of a wide range of climate services. Major new and strengthened research efforts are required to increase the time-range and skill of climate prediction through new research and modelling initiatives. This aim also to improve the observational basis for climate prediction and services, and the availability and quality control of climate data.

For all these considerations becomes fundamental to support the Global Framework for Climate Services proposed by WMO initiative in a way to integrate the information system that is also nowadays sorrowing by some imperfections that damage its efficient utilization.

The basis of GFCS are related to several studies in climate, started in the latter half of 19<sup>th</sup> century and coordinated through International Meteorological Organization (1873) and its successor, World Meteorological Organization. All these observations in addition to other ones, coordinated through Global Climate Observing System (GCOS), and recently the Group of Earth Observations (GEO), have provided scientists still invaluable information; over the years the World Climate Research Program (WCRP), along with the International Geosphere Biosphere Program (IGBP) and other research initiatives, has contributed to

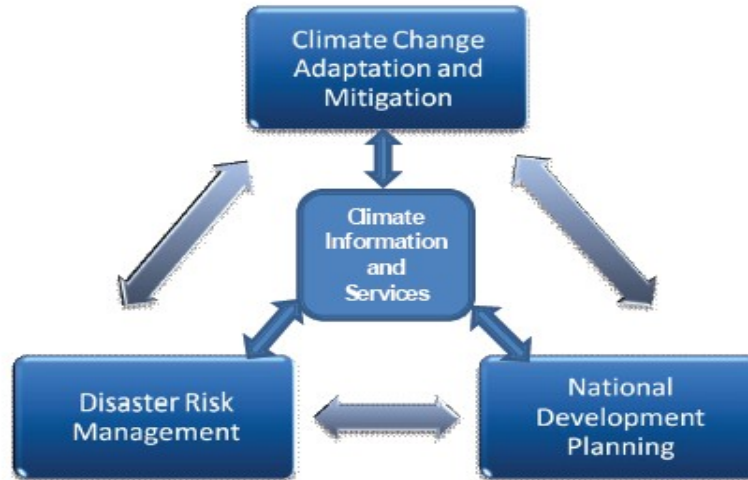
the understanding of the Earth system with more adequately competences.

Now, the increasing comprehension of the earth system functioning and the development of the awareness of climate change problem makes imperative for society to arm itself with appropriate measures to fight the inevitable increase in climate variability in a way to understand it first, and then predict it and discover their influences. Achieving this goal means provide decision-makers with correct sources of information about the variations and changes in the climate system including their causal mechanisms as well as their potential environmental and socio-economic consequences. Recent advances in the development of climate information from a science-based perspective, coupled with an increased awareness within climate-sensitive sectors about their vulnerability, bring the management strategies into risk management one, in an effort to increase socio-economic benefits.

Successful CRM requires accurate knowledge about the sensitivity to climate of the various users, identification of their needs for climate information and certain provision of this information, effective two-way communications, decision support tools, and appropriate policy frameworks for action.

The following illustration gives a basically representation of the GFCS concept in a macro-perspective, look at the main connection including climate information and services (Figure 8).

*The role of Climate Information and Services in sustainable development*



*Figure 8 describes the role of Climate information and Services in planning decisions for adaptation to climate risk and management. Source: GFCS – Concept Note, p. 5.*

It is important to mention that the requirements of users regarding climate sensitive sectors have to be taken into account in generation and delivery of climate information, to enable the users to develop “proactive” strategies for climate risk management, sector planning and adaptation measures. The basic scientific and technical climate information must also become user-focused and support climate sensitive decisions, in addition to be provided with a certain degree of comprehension. In this sense easy access, consistency and pertinence of the information to users’ needs are fundamental to ensuring integrated information into decision-making processes.

Significant steps have been taken towards setting up the infrastructure, programs, and partnerships needed at global, regional and national levels for fulfilling the climate information needs of all regions and sectors. Many organizations and several methods and programs have been adopted for the accomplishment of adaptation policies at all scales,

local as well as global ones.

The following steps, pointed out from the Global Framework for Climate Services, include some essential building blocks for the development and delivery of climate information and services.

This special list starts from the World Climate Programme that, particularly through the Climate Information and Prediction Services (CLIPS) project, demonstrated the value of climate information and prediction services and made efforts to build capability to predict climate on monthly, seasonal and inter-annual time scales by the utilization of the existing skills; in the past few years, WMO, through its Members, has designated Global Producing Centres of Long-Range Forecasts (GPCs), and other efforts to establish a worldwide network of Regional Climate Centres (RCCs) to provide real time inputs to National Hydrological and Meteorological Services (NMHSs) to generate climate information are taking shape.

The Regional Climate Outlook Forums (RCOFs) are operational in several parts of the world with an overarching responsibility to produce and disseminate regional assessment about the state of the regional climate for the upcoming season. From the perspective of working with users of climate information, the Regional Climate Outlook Forums (RCOFs) produce and disseminate a regional, consensus-based assessment of the state of the regional climate (i.e. a climate prediction) for the upcoming season. Built into this process is a regional networking of the climate service providers and user-sector representatives (including media), within which users can interact with climate experts and discuss technical information and products (analyses, forecasts, probabilities, etc.) with the information providers.

The NMHSs from the 188 Member states and territories of WMO are the essential core network underpinning the entire framework. Over the years, they have developed the mechanisms to produce and deliver the weather services, which have improved over the years. Some of the NMHSs, in collaboration with other agencies are also providing climate

services in the countries. Many NMHSs, experiencing the advantages of RCOFs, are also instituting national Climate Outlook Forums (COFs), for interface with national users.

The Framework for Climate Services we are taking in exam, provided by World Meteorological Organization, focuses its goals in “the development and provision of relevant science-based climate information and prediction for climate risk management and adaptation to climate variability and change, throughout the world” or “the development and provision of relevant science-based climate information and facilitate its use for climate risk management and adaptation to climate variability and change, throughout the world”<sup>21</sup>.

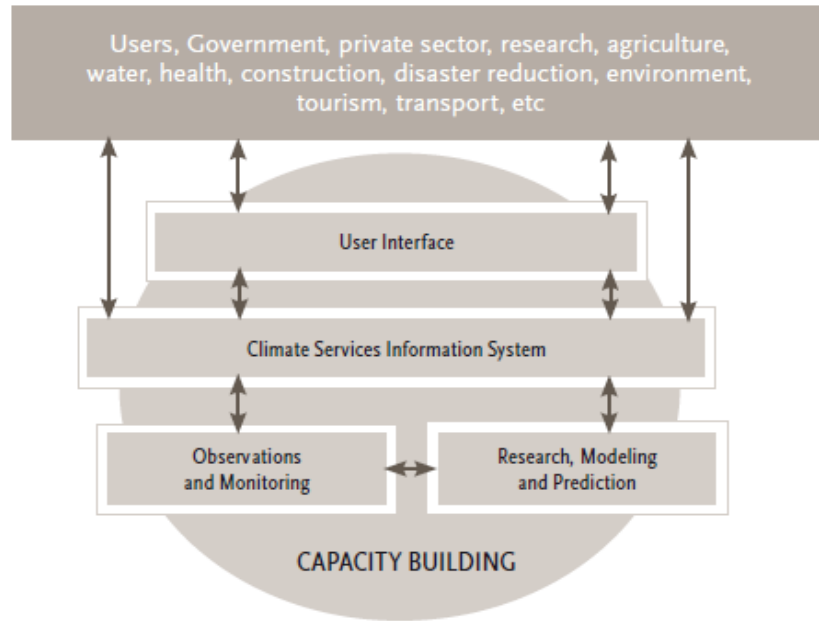
The actions required in according to these goals consists in enhance in understanding of and responding to climate risks and associated opportunities; improve the quantity and quality of climate information; provide information at all scales in a timely, understandable and easily manner; promote a continuous and correct use of these information for economic efficiency, social well-being and development of policies for sustainable development.

The main GFCS is composed by four main components: “User Interaction Mechanism”; the “World Climate Service System (WCSS)”; “Research”; and “Observations”. Close interactions among the cited components is crucial to allow the Framework functioning and can be represented by the following illustration (Figure 9), that shows also the importance of the interactions in addition to the fundamental role covered by capacity building in the interactive process.

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21 Source: GFCS – Concept Note, p. 7.

***A schematic of the components of the Global Framework for Climate Services***



***Figure 9*** provides a scheme representing the structure of GFCS in its four components.

*Source: GFCS by WMO, 2011, p. 9.*

It is recognized that few governments have utilized climate services that are able to engage national needs and demands. Fundamentally there is a consolidated awareness that a gap exists in engagement and communication between service providers and service application. Climate research and services communities are trying to develop knowledge and related information products from a disciplinary research perspective, largely uninformed about stakeholder needs, in a way to remove the mentioned gap. At this purpose, the “User Interaction Mechanism” of the GFCS aim to:

- Promote, facilitate, coordinate, and conduct focused interdisciplinary research and development needed to understand the sensitivity of activities in vulnerable socio-economic sectors to climate variability and change;

- Identify user requirements for climate information, and organize these for future development work;
- Demonstrate, capture knowledge, share and disseminate the utility of research in practical settings and contribute to improved policy in managing climate risk;
- Facilitate user uptake and use of the climate information, and to continually provide user feedback into the system to drive its growth and improvement; and
- Build capacity, globally, in uptake of climate knowledge and information.

User interaction mechanism would be required at various scales (regional, national, global) and it is also sector-specific. So it is important to address the sector-specific and user-specific needs according to the local conditions in a way to use this function efficiently. The players involved in user interaction mechanism are for example UN System, International Climate Research Institutions, Sectoral Research Institutions, concerning the Global scale; Regional Development Institutions, Regional Climate Centres, for Regional scale, and National Development Ministries, National Research Institutions, NMHSs and other climate related agencies in National systems. Furthermore institutions like Universities and NGOs could interact in all these local scales.

Especially to help user sectors shift from a “reactive” to a “proactive” approach in climate risk management, there is a need to improve the mechanism in particular at the global level, through enhance the coordination between different research networks.

Given that, climate processes are global in character and operate on a wide range of space-time scales, the flow of information from global to local scales, and on the contrary side too, is essential and has to be ensured; in particular it is necessary to put in place appropriate institutional mechanisms to generate, exchange and disseminate quality information at all hierarchical levels.

To address these requirements, a World Climate Service System (WCSS) is proposed by WMO. It depends on a network of global, regional and national institutions that develop

and provide the climate information; it will take advantage of, and further develop, existing infrastructure and mechanisms provided by existing institutions. The networks of global, regional and national entities including GPCs, RCCs and national climate centres, therefore, will serve as the foundation of the WCSS.

For WCSS, the main providers of climate information are National centres. At this level climate activities are often shared between governmental and non-governmental institutions, universities and national research institutes. In most of the countries their National and Meteorological and Hydrological Services (NMHSs) support several functions in generate and delivery of the climate information at higher hierarchical scales: linking to the regional and global centres; exchanging climate data and exchange climate data and operational products with regional and global centres; downscaling global and regional climate information, including diagnostic (present and past) and prognostic (future) information at various time scales; monitoring, conducting climate watch and issue weather warnings and climate advisories to support national early warning systems and disaster risk reduction activities and programs; and developing climate services at the national level for various sectors.

Regional Climate Centres (RCCs) are regional institutions with capacity and mandate to develop high-quality regional scale climate products using global products and incorporating regional information. RCCs will, with the new knowledge and tools developed through applied climate research, generate regional and Sub-regional scale products for the congenial local situation. Typically RCCs functions are those who: downscale, interpret and assess relevant prediction products from global centres; monitor regional climate variability and extremes; implement and conduct Climate Watches; develop quality-controlled regional climate datasets for temperatures (minimum, maximum and mean) and for total precipitation, rainfall and snowfall; share regional and sub-regional products and information; and downscale climate change scenarios.

At the global level WMO included in Climate Services Framework centres like the Global



Producing Centres (GPCs), the World Data Centres (WDCs). The first are operational centres producing long-range forecasts of global large-scale fields of temperature, precipitation and other major climate variables. Some of the existing GPCs are likely to extend their capability from seasonal to longer time-scales.

In addition, there are a lot of data centres having global/international coverage for specialized data, such as meteorology, climate, oceanography, radiation, remote sensing, atmospheric chemistry, environment, etc. These data sets cover land, sea, surface and upper air domains. Reanalysis of historical climate data using a constant “state of the art” techniques and model has helped enormously in making the historical record more homogeneous and adapt for various uses. These data centres are integral part of the network.

The WCSS place high priority on development of climate information addressing sector-specific requirements and on improving quality and understanding of these information. It is also fundamental to apply correctly the information into decision-making processes.

### ***3.2 Climate Information and Services across different uses and methods***

#### *3.2.1 Improving Climate Services at Global Level*

The 20<sup>th</sup> Century has brought concrete progress in understanding of the climate system. The World Climate Research Programme (WCRP) with WMO, the International Council for Science (ICSU), and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, together coordinate international climate research and has contributed invaluable to climate science in addition to the IPCC assessment process.

Despite these advances in modelling, prediction and earth system sciences, complexities of climate system processes and their interactions are not discovered at all. Current climate models are known to have characteristic limitations and to be subject to a range

of biases and errors. As explained in the Fourth Assessment Report of IPCC, there is a need to identify and understand the important processes that control climate systems, and how they interact with broader community issues. Increasing skills in climate prediction (from seasonal to decadal), climate modelling, estimating the uncertainties of climate predictions and projections, both at the global and regional levels, requires extensive research. It would require better representation of Earth System processes in a fully coupled manner in climate models, to reduce the uncertainty.

Moreover, decision makers are increasingly demanding climate information for adaptation and for assessment of impacts and vulnerability. They require predictions on seasonal, inter-annual to multi-decadal time-scales as well as improve their spatial resolutions. In addition, there is a growing demand for information on climate change scenarios at the regional and national level.

It is both necessary and possible to revolutionize regional climate prediction and downscaling<sup>22</sup>: necessary because of the challenges that changing climate offers, and possible because of growing accomplishments in predicting of weather and climate.

At global scale the improvement point out by research institutions seems to be evident, while at regional and local level estimates of the climate-related risk is constrained by technical and capacity limitations. Transition, bringing studies of global climate variability and change to applications at the regional level will be a fundamental challenge to pursue, addressing a several number of existing gaps that separate information providers from decision-maker needs.

To reinforce the international, regional and national cooperation required to strengthen climate research it is needed to:

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<sup>22</sup> Downscaling refers to the process of adjusting predicted information to be representative of spatial scales below which they are produced by climate models. This approach increases the probability that the information is relevant to decision-makers working at regional scales, that is, spatial scale smaller than those at which the climate models function. In few words, downscaling makes information more relevant to stakeholders in their realms of decision-making. Source: R. Munang et al. 2010.

- develop improved methodologies for the assessment of climate impacts on natural and human systems through an integrated approach by including greater biological and chemical details would need to be included;
- characterize and model climate risk on various time and space scales relevant to decision making and improve the skills in prediction;
- enhance spatial resolution of climate predictions including improvements in downscaling and better regional climate models;
- develop better understanding of the linkages between climatic regimes and the severity and frequency of extreme events;
- streamlining the linkages between Research and operational service providers.

Developing such integration framework require to adapt infrastructure in the way to manage this type of problem as well as establish a specific focus point on human capital, to provide the necessary links between scales, sectors and agents. This would help build the knowledge-base, tools, models and methodologies essential for the development of sector specific climate information for decision-making.

The National Meteorological and Hydrological Services (NMHSs) around the world, in cooperation with other national, regional, and global partners, undertake climate related observations that underpin the predictions, analyses, assessments and other information critical to decision-making for adaptation.

The Global Climate Observing System (GCOS) established in 1990 as a joint initiative of WMO, the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the International Council for Science (ICSU) and UNEP, has further raised awareness to all nations participating in the United Nations Framework Convention on Climate Change (UNFCCC) of the importance of climate observations. Through a partnership among a number of players, including NMHSs, GCOS promotes observation of the essential climate

variables (ECVs). It has developed important principles to guide climate observations and has identified those variables that must be observed in order to better understand climate with its variations and changes. Built on the World Weather Watch, Global Observing System (GOS), the Global Atmosphere Watch (GAW), the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), and the Global Earth Observation System of Systems (GEOSS), GCOS address the requirements of all societal benefit areas to meet their climate related observation needs<sup>23</sup>.

One of the major challenge in monitoring the climate system and in improving its understanding is developing and maintaining observing programs, particularly in remote regions of the world. Further, many developing countries and economies in transition are greatly challenged in implementing and sustaining even the most basic observing systems. As a result the spatial coverage of in-site climate observing networks, on a global scale, has been deteriorating since the 1990s.

Some of the observing networks have been developed through research initiatives. They have over the years become quasi-operational and have contributed to the advancement of climate prediction and analysis leading to a much narrower level of uncertainties. These observations need to be continued to be supported and, where possible, have to be converted into operational programs.

In practice, activities under the government of these institutions would improve the existing mechanisms and ensure that climatic variables are evaluated in the right way. Developing countries will need assistance, through the realization of the correct supports, in order to do so.

In addition to climate observations, it would be necessary, especially at country levels, for decision-makers to have access to high quality socio-economic data, environmental and biodiversity data to conduct impacts studies and assessment of adaptation options. In that way it would be interesting to develop collaboration within the groups that develop these

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<sup>23</sup> <http://gcos.wmo.int> for further information about GCOS.

datasets, for example with mechanisms for merging data for joint studies on impacts and vulnerabilities. The Global Framework for Climate Services would focus in developing these synergies with stakeholders for the creation of sectoral, socio-economic and environmental datasets.

It is also important, to facilitate an efficient use of climate information, that in sector specific context all sectors systematically collect and manage relevant information for their core activities; even if some of these datasets are not easily available, and their availability may require high level government decisions and commitments to changes in policies for data sharing and interoperability. Complexity is a constant in treating these information, and have not to be an insurmountable limit for decision-makers, but a motivation to improve synergies within the actors that manage them.

The only credible solution for create real responses about climate change issues seems to be the development of a high degree of international cooperation. How nations participate in international climate initiatives determine how successfully climate change challenge is faced by our society.

Cooperation is needed in building user interaction mechanism as in manage technical information and communicate them to the stakeholders. For example, to form user interaction in the application of climate information to develop decision support tools for water resources, agriculture and the disaster risk reduction communities could create closer collaboration and cooperation with other UN agencies such as the Food and Agriculture Organization (FAO), UNESCO, UNWater, Intergovernmental Oceanographic Commission (IOC), the UN International Strategy for Disaster Reduction (ISDR) and with partners from development and humanitarian communities etc.

For observing the climate system and for transmission of data and information, WMO entities work closely with Space Agencies, developers and suppliers of observing technologies, communications companies, etc. GCOS and GEO provide the required

platform for observations; as in Earth System model studies, WCRP<sup>24</sup> will have to develop stronger links with other research coordination mechanisms such as International Geosphere Biosphere Programme and International Human Dimensions Programme on Global Environmental Change.

Global partnerships among regions are important to share knowledge, experiences and techniques; governments in particular have, in this perspective, the fundamental role in ensure the access of scientifically credible and adequate information on climate prediction and change.

In terms of communication the Framework for Climate Services identifies partners in a variety of media and would seek the commitment of new partners in these efforts, improving that and ensuring the relationship with existing partners continues to be strong and productive. Strategic collaboration with communications entities and the major media groups would aim to facilitate public awareness up to reaches climate-sensitive socio-economic communities. At the national level, the Framework collaboration with national and local media are encouraged, in the way to bridge the communication gap between climate scientists and other sectors, and to broaden the scope of adaptation measures.

Now, the Global Framework for Climate Services provided by WMO could be the right vehicle to guide and coordinate the effort to create an end-to-end system for providing climate services and applying them in decision making at every level of society. For a modest investment, and by building on existing systems and capacities, most people believe that implement this Framework could achieve great benefits for societies in terms of reduced disaster risks, increased food security, improved health, and more effective adaptation to climate change. And great benefits also in terms of development and well-being in all countries, but particularly for the poorest and most vulnerable<sup>25</sup>.

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24 World Climate Research Program.

25 The report of the High-level task-force for the Global Framework for Climate Services, 2011.

A WMO task-force worked in consultation with all relevant actors to assess the current state of global climate service provision and identify opportunities for improve the Framework; the output given by task-force working group, proposes five near-term implementation objectives: (1) establish mechanisms to improve and consolidate the global cooperative system for collecting, processing and exchanging observations and for using climate-related information; (2) design and implement a set of projects that target the needs of developing countries, particularly those currently least able to provide climate services; (3) develop strategies for external communications, resource mobilisation and capacity building programs; (4) establish internal working methods, particularly for communications and for debating and deciding on implementation priorities, including for the observations, information systems, research and capacity building components; (5) fix targets and set procedures for monitoring and evaluating the performance of the Framework.

In undertake these improvements it' s important to adopt several principles, in a way to create real benefits for social well-being. These principles are the following<sup>26</sup>:

- All countries will benefit, but priority shall go to building the capacity of climate-vulnerable developing countries.
- The primary goal of the Framework will be to ensure greater availability of, access to, and use of climate services for all countries.
- Framework activities will address three geographic domains; global, regional and national.
- Operational climate services will be the core element of the Framework.
- Climate information is primarily an international public good provided by

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[http://www.wmo.int/hlt-gfcs/downloads/HLT\\_book\\_full.pdf](http://www.wmo.int/hlt-gfcs/downloads/HLT_book_full.pdf) .

26 Source: Climate Knowledge for Action: A Global Framework for Climate Services – Empowering the Most Vulnerable. WMO, 2011.

governments, which will have a central role in its management through the Framework.

- The Framework will promote the free and open exchange of climate-relevant observational data while respecting national and international data policies.
- The role of the Framework will be to facilitate and strengthen, not to duplicate.
- The Framework will be built through user – provider partnerships that include all stakeholders.

In synthesis, to develop capacity building will be an essential goal in successful implementation of GFCs; at this purpose the WMO task-force proposes some capacity building projects, consisting in linking climate users and providers, building national capacity in developing countries and strengthening regional climate capabilities.

Efforts will be made to develop dialogue between information providers and users in the way to achieve long-term success. Other key issues will be the improvement in climate observations quality and in the rate at which research results flow to services, in addition to improve the quality and the relevance of climate services.

### *3.2.2 Climate Services in Italy*

Focusing on Italy, on 27 February 2012, nearby the “Direzione Generale per lo Sviluppo Sostenibile, il Clima e l’Energia”, was held a meeting in which experts at the technical level of the leading national research institutes, in order: “Istituto Superiore Per la Ricerca Ambientale”, “Istituto di Ricerca sulle Acque” of CNR<sup>27</sup>, “Istituto di Scienze dell’Atmosfera e del Clima” of CNR, “Istituto di Biometeorologia” of CNR, ENEA<sup>28</sup>, “Istituto Nazionale per l’economia Agraria”, “Consiglio per la Ricerca in Agricoltura”, “Fondazione Enrico Mattei”,

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<sup>27</sup> Consiglio Nazionale delle Ricerche.

<sup>28</sup> Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile.



“Istituto Nazionale di Urbanistica”, “Istituto Nazionale di Geofisica e Vulcanologia”, “Stazione Zoologica Anton Dohrn”, and “Centro Euro Mediterraneo per i Cambiamenti Climatici (CMCC)”, in a way to compare the state of scientific knowledge about the climate scenarios and the impacts of climate change, vulnerability and adaptation<sup>29</sup>.

This meeting represents a first step in developing a national strategy for adaptation to climate change, consistent with the deadlines set in the White Paper of the European Commission<sup>30</sup>.

Exploring some activities that take place in these research institutes regarding climate services in particular, we can mention for example CMCC, that is employed in researches about climate science and policy through a network structure that includes research divisions, partners and associated centres. The CMCC aims to increase knowledge in the field of climate variability, its causes and its consequences, through the development of high resolution simulations with global models analysing the Earth system and regional models, with particular attention to the Mediterranean Area.

Research conducted by the CMCC ensures the long-lasting quality of products and tools used, which are characterized by a high degree of reliability in terms of utilization, maintenance and security and are also made available to the scientific community for further studies of impact and investigation of climate change.

The simulations obtained by the numerical models developed, tested and maintained by CMCC, can be and often are used to study the multiples impact of climate change for example on the economy, agriculture, coastal, marine and terrestrial ecosystems. The Center is in constant dialogue with international research centres and promotes its constant growth, innovating step by step methods and content of research.

The CMCC plays also a reference role for our country in the international climate research,

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<sup>29</sup> The documents constituting the interventions from the participants are available at [http://www.minambiente.it/home\\_it/menu.html?mp=/menu/menu\\_attivita/&m=Clima.html|\\_cambiamenti\\_climatici.html|Informativa\\_DGSEC.html](http://www.minambiente.it/home_it/menu.html?mp=/menu/menu_attivita/&m=Clima.html|_cambiamenti_climatici.html|Informativa_DGSEC.html).

<sup>30</sup> <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:it:PDF>.

acting as Italian focal point for IPCC<sup>31</sup>.

Concerning for example an other Italian institution like CNR, inside it the DTA<sup>32</sup> provides the technical and regulatory support of CNR afferent and participants, for the formalization connected to the implementation of the National Research Program, the management of administrative activities about the institutions, the implementation of agreements, conventions and contracts for the functional availability of resources and recognition of the role of the CNR as one of the main research institution in the country.

The Department also ensures the representation of the CNR within international bodies for the coordination of activities and research projects, and also provides the disclosure and dissemination of scientific information through a dedicated website.

One of the actions undertaken by the national DTA was those to achieve coordination within the activities related to integrated and inter-operational management about environmental data produced by the National Research Council, called GIIDA<sup>33</sup>. The project objectives were: 1) consolidating and strengthening the system of observation of the CNR, 2) Networking of CNR for data sharing, 3) data assimilation into models of simulation and forecasting, 4) creation of a "federated system" management, processing and evaluation of environmental data (CNR, national and international). The strategic approach of the DTA is based on the transversality of the fields of investigation in order to identify and better understand the interactions between divers systems and phenomena<sup>34</sup>.

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31 <http://www.cmcc.it/cosa-facciamo> .

32 Dipartimento Terra e Ambiente.

33 Gestione Integrata e Interoperativa dei Dati Ambientali.

34 [http://www.cnr.it/dipartimenti/AttivitaDipartimento.html?id\\_dip=1](http://www.cnr.it/dipartimenti/AttivitaDipartimento.html?id_dip=1) .

## **CHAPTER 4**

### **ABMs FOR DECISION-MAKERS**

Nowadays it is clear that integrated analysis of climate change represent fundamentally a problem of complex, bottom-up and multi-agent human behaviour. It is also well established that the increasing complexity driving these dynamics requires methods and models that are able to combine social and ecological systems in a right way.

Past and contemporary literature point out Agent-Based Models (ABMs) as a promising models for socio-environmental simulation.

From Bharwani et al. (2005), Agent-Based Modelling illustrates how macro-level behaviour can emerge from a various type of rules which inform decisions at the local, individual level. ABMs can be used to establish which patterns of strategic behaviour emerge as a result of local responses and whether such emergent phenomena account for a clear understanding of the original field data.

There has been much discussions among experts in the field of social simulation, in particular regarding the reason for which they should be built, as an implementation of theory rather than be considered more important than the same theory. ABM seems to create a sort of feedback process between observation and theory in a way that the two issues became important as a combined process, valuable only in its totality.

The literature mentioned in the next paragraph shows the potential of this modelling in couple social and environmental models, incorporating the influence of local decision-making in the dynamic system, and studying the emergence of collective responses.

Mainly referring to Balbi and Giupponi (2010), we present ABMs as a consolidated interdisciplinary approach for the bottom-up exploration of climate policies, especially for its focus on adaptive behaviour and heterogeneity of the system's components.

#### **4.1 ABMs Storyline**

There is an increasing awareness that traditional economic approaches are not the better methods to explore context that are affected by climate change dynamics, involving a degree of complexity that are not captured by the mentioned methodologies, in particular referring to social behavioural patterns.

In reality responses to climate change have to be found in humans behaviour at all, as the properly notion of Socio-Ecological Systems (SESs) remembers.

The first researches in computer science modelling showed how Complex Adaptive Systems can be represented by Multi-Agent Systems (MASs), derived from Distributed Artificial Intelligence (DAI), firstly used in order to reproduce the knowledge and reasoning of several heterogeneous agents that need to coordinate with the aim to jointly solve planning problems. However these methods have not the character and the possibilities to fully model SESs determinants.

To date, a various body of work on ABM exists, involving several sectors like sociology and social processes, economics and finance and in a set of environmental issues including land use and cover change, ecology and natural resource management, agriculture, urban planning and archaeology. Nevertheless, the presence of useful publication on ABM in climate change arena is limited. The development of researches in this field started only recently with many project that could bring to several potential publications in the next future. The differences stands on the fact that, while first researches were based on deterministic mode, contemporary ABM analysis use exploratory methods in new and more veritable conditions of deep uncertainty.

There literature provides different definitions of ABMs, depending on the different approaches that can be used. This diversity consists in the complexity of the interactions to be modelled, involving multiple interdependencies among agents and their environment, across time and space scales.

There are a lot of source of complexity in ABM arena, like for example heterogeneity, considering experiences, values, abilities, resources, etc.

One of the central tenet in ABM researches is represented by “emergence”; an emergent property is a macroscopic outcome resulting from synergies and interdependencies between lower hierarchical level system components. Emergence is the issue that characterizes a complex system, and it isn’t a quality that can be treat analytically from the attributes of internal component, being strictly linked with interdependence inside the considered context.

Emergence and cross-scale hierarchies are therefore strongly related. Identifying emergence may require to understand as much as possible cross-scale interactions and building theses across modelling rather than limited the analysis to a single and independent scale.

Complexity is often be mentioned because of its derivation taken directly from agents internal world, their mental model or architecture, which describes their cognition and learning capacity. Agents behaviour is conditioned by bounded cognition, that mirrors the limited perception they have of the environment around them. So, agents are not meant to be omniscient and fully rational utility maximisers as, for instance, the “homo economicus” aims to be. It’s by ABM that these complexity can be considered in the appropriate way, incorporating the salient characteristics of actual human decision-making behaviour, including the determinant agents capacity of learning from past experiences. This combination, between behavioural complexity and that related to interactions and heterogeneity, allows the representation of adaptation in agent-based models and simulations, at both micro and macro scales.

Literature tries to point out the points of convergence between different disciplines engaged in Agent-Based Modelling of Socio-Ecosystems and a framework to classify them. We mention, agree with Balbi and Giupponi (2010), some streams of research that can be

found in each of the three scientific domains that constitute the triple bottom line of sustainability (social, environmental and economic domains). These several field of research can represent a framework that could well describe the scientific behaviour in operating with Agent-Based Modelling.

The first field of research is named “self-organization and co-evolution of the system”, that focus ABMs on the self-organizing capabilities of the system under study, in particular on how agents’ behavioural rules influence their co-evolution and the system’s structure.

The researches in “diffusion processes and networks formation” instead, analyse how micro-level interactions and transmission of information lead to the emergence of specific structural phenomena.

The third stream of research, “modelling organizations, cooperation, and collective management” focuses on how the system's topology and structure influences its own behaviour; in particular it is interested in which structure stimulate cooperation in the benefit of the collective.

“Parallel experiments” include those applications that compare computational and empirically observed agents and structures in order to improve the representation of the system under study. This stream has strong linkages with the issue of model validation.

The studies in “agent's architecture” deals specifically with agents behavioural complexity. The main issue is how to represent the decision making of the agents and, ultimately, evolution and learning both at a micro- and macro-level.

Finally “programming” researches represent essentially a cross-cutting issue given the shared computer based approach. Object Orienting Programming techniques (OOP) are often advocated as a crucial mean for constructing an environment in which users can easily tailor models designed to suit their own particular research agendas.

We can say that the first three streams define the main research questions of an ABM application and, therefore, tend to be mutually exclusive, while the remaining can be understood as necessary accessories and tools among the ABM movement, so they could

be used according to a logic of continuous interaction.

Some general considerations can be done about ABMs uses and characters, starting from the point that more than half of the studies we have presented above concern the self-organization and co-evolution of the system<sup>35</sup>. We should not to be surprise about that, thinking this is the stream that paved the way to the application of ABM to social processes, meaning that the first examples of ABM dealing with climate change are following the most consolidated path of development.

It is quite evident that ABM own the abilities to model local, regional and global systems both at a very abstract or more realistic level. In this sense we can distinguish between two typologies of ABM that have to deal with climate change: the majority of these, that focus on adaptation and that analyse regional and local systems, and few global models, that are concerned about mitigation. In the first case the level involved in the studies is the community (or network of communities) level. In the second case there is much more aggregation, even if a certain degree of heterogeneity is introduced by means of the agent-based thinking. In any case, there are no case in which adaptation and mitigation are treated together referring to ABMs.

Agents involved in several models have the role to represent various human actors at different hierarchical levels. In general Agent-Based Models try to limit the number of agent's types, in order to limit the degree of complexity. In general most of ABMs employ between 1 and 3 agent's classes.

About the notion of environment used, it can be treated in a variety of ways. In the majority of the cases, these models rely on equations or indicators, which can be defined as sub-models describing theoretical spaces of interaction. Most of the models employ economic sub-models while less others are based on non-spatial sub-models.

As we have already mention, emergence remains the central tenet of Agent-Based

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<sup>35</sup> Co-evolution theory stresses that bio-physical settings and institutional features change together; the evolution of each is reflected in the evolution of the other.

Modeling dealing with climate change. To explore emergence constitute the key issue in these analysis, as a means for discover the dynamics that intrinsically rule the entire systems. Most of the models identify the economic outcome as an emergent property of the system; other emergent properties are linked to different aspects like for example demography. The logic behind this studies, belonging to the stream on modelling organizations, cooperation, and collective management see these outcomes as a consequence of emerging behaviours.

An other character we have previously plenty exposed concern the complexity of interactions that ABMs try to capture. It is well established the key role played by this aspect, and the study evidences show most of the incorporate interdependencies across spatial and temporal scales.

In contrast with the mainstream literature on climate change economics, ABMs don't provide a "representative agent", that instead varies depending on demographic characteristics, location, own endowment, individual abilities, perception of the world, attitudes and behaviour. Clearly, the level of diversity is linked to the level of detail of the model, so ABM ability can be more effectively employed in the local dimension. However, some degree of aggregation is always necessary.

In ABMs the spatial representation of the environment is not the prevailing option. Most of the models are not spatially explicit even if, as just mentioned, they obviously exists.

Relative to time, several models are run for a time period of approximately 100 years, where every year is a time step. This is in average a time period of significance in order to capture climate change effects both in adaptation and mitigation terms. However, there can be exceptions in both directions.

Various options for modelling behaviour exist; one is represented by goal oriented heuristic rules, drawn from field work, expressed in form of statements; a second solution are to express behaviour on utility functions expressed in form of equations, on the basis of economic theory. Different studies could prefer the first or the second methodology, on



the basis of the structure of the systems analysed.

ABM main trap in climate change arena is represented by validation or verification actions<sup>36</sup>. A lot of models don't treat these aspects because of the high level of abstraction, which impose a serious limitation to achieve any form of model testing. In fact from validation and verification point of view, several models are not fully satisfying even if some have produced significant efforts.

Finally, regarding technical aspects, a large part of models make use of an ABM platform like "Repast", "Netlogo" or "Vensim" for example, to explore system dynamics.

Summarizing, ABM is maybe the most promising modelling approach for sustainability science. The intrinsic multidisciplinary methodology justifies its application to model SES, in which humans and the environmental systems co-evolve and a significant integration of the knowledge belonging to different domains is required. The streams of researches cited from Balbi and Giupponi (2010) analysis, support the idea that ABM is an appropriate bottom-up methodology for the exploration of climate policies; in particular ABM seems particularly well suited to the analysis of adaptation to climate change about local systems, and the collection of some of this researches compose the main body of work on agent-based models dealing with climate change.

In other way ABM can also be implemented in top-down orientations where the main issue is mitigation at a global level. A further development in this field of research could be the jointly analysis of adaptation and mitigation exploiting Agent-Based Modeling.

It is well established that the main advantages of ABM applied to climate change related issues are the abilities to take into account adaptive behaviour at individual or system level and to introduce a higher degree of heterogeneity resulting into a more natural representation of the system, compared to equilibrium-based models. In the context of

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<sup>36</sup> Test usually carried out by comparing model outputs with an independent data set (not the one used for calibration, that compare observed data and model outputs).

climate change adaptive behaviour means to allow the SES to react, which is a crucial aim in order to avoid unrealistic or meaningless results.

In addition, ABMs have also the fundamental capacity to overcome the problem deriving from heterogeneity that, if neglected, could lead to the loss of crucial drivers of change.

To date the open issues about the application of Agent-Based Models in climate change arena remain numerous, but above all we can mention two aspects that could be implemented at first, one is to think about a dedicated platform, for the future, which could simplify the modelling options into local and global systems and possess a library of household type agents and of specific socio-cognitive models of adaptation. In that manner probably an improvement in accessibility of the methodology to those who cannot spend too much time in learning a programming language could be achieved.

Second, since a communication barrier remains evident, efforts would be made to find a common communication standard of the models analysed.

#### ***4.2 Agent-Based Modelling in Adaptation to Climate Change***

As already said, Patt and Siebenhuner (2005) reaffirm the idea that poses Agent-Based Modelling as a technique that could simulate complex systems that allows the modeller to investigate both the potential for and the sources of emergent properties: behaviours of the system resulting quite different from the behaviour of any of the elements within it. Problems well suited to investigation by agent based models are those with many people solving a similar problem where their individual responses to the problem influence the choices that others make, where new technologies may emerge to assist them solve the problem, and where social dilemmas exist. These features are inherent in many problems of adaptation to climate change. Agent based modelling can not predict the future of a complex adaptive system, and nobody else can do this precisely, but it can offer insights into the relationship between features of current systems and the range of possible future

adaptations that will be likely in response to climate change.

As regarding adaptation along with many other economic phenomena, the extent to which a system adapts to external changes such as climate change impacts is an emergent social phenomenon that results from the joint decision making of many separate decision makers in definite spatial and temporal scales. ABMs can offer insight regarding the properties that emerge from actor's relationships.

Always reporting the indications provided by Balbi and Giupponi (2010), in their work about ABM methodology analysis, published from International Journal of Agent Technologies and Systems, following are presented several researches that develop the issue of ABM applied to climate change concepts, in a way to provide an exhaustive framework about consolidated analysis in the field of adaptation to climate change.

At this purpose, Janssen and de Vries (1998) are specifically involved in the analysis of the behavioural aspects of ABM applied to climate change adaptation, mainly basing their analysis to the fact that agents are groups of decision makers who operate at the international level and behave in different ways towards climate change.

Dean et al. (1999), Werner and McNamara (2007), Entwisle et al. (2008) and Filatova (2009) instead are concerned with ABM and land use. Dean et al. (1999) is an example of ABM of a local socio-ecosystems, including climate change elements in order to simulate human responses and the outcome of adaptation. The resulting model represents the behaviour of culturally relevant agents on a defined landscape in order to test hypothesis of past agricultural development and settlement patterns. Werner and McNamara (2007) deal with the concept of how the economic, social and cultural factors surrounding the human response to river floods, hurricanes and wetlands degradation affect a city landscape. Entwisle et al. (2008) focus on the responses to floods and drought at a regional level in terms of agricultural land use and migration, in particular taking into account social networks. Filatova (2009) included climate change related risks in an agent-based land market for coastal cities, which aim to simulate the emergence of urban land

patterns and land prices as a result of micro scale interactions between buyers and sellers. Berman et al. (2004), Bharwani et al. (2005) and Ziervogel et al. (2005) are the only published empirical field studies, which explicitly aim at exploring local adaptation in the context of climate change and sustainable development by means of ABM. Berman et al. (2004) investigate how scenarios associated with economic and climate change might affect a local economy, resource harvest and the well-being of an existing community. Bharwani et al. (2005) assess whether individuals, who adapt gradually to annual climate variability, are better equipped to respond to longer-term climate variability and change in a sustainable manner.

Barthel et al. (2008) developed an ABM framework for water demand and supply future scenarios where the socio-ecosystem is enabled to react and to adapt to climate change. Hasselmann (2008), Beckenbach and Briegel (2009) and Mandel et al. (2009) studies concern macroeconomic models which employ, more or less explicitly, an agent-oriented framework in dealing with growth and climate change at a regional to global level. Hasselmann (2008) with this method introduces few representative actors in a macroeconomic model of coupled climate socioeconomic system structured following a system dynamics approach. His focus is on the evolution of this system according to behaviour of the agents pursuing different goals while jointly striving to limit global warming to an acceptable level. Mandel et al. (2009) developed an agent-based model that concerns a growing economy where growth is pushed by the increase of labour productivity proportionally to investments.

A specific sector in which ABM are applied with consistent results regarding adaptation to climate change is probably the agricultural field. In these models several input factors can be taken into account; basically the input factors involved are climate datasets, representing climate information. The aim of these studies is some case those of understand how agents could make use of climate inputs such as expected precipitation or future temperatures in a way to adapt as well their activities. Agent-Based Models

support this type of analysis providing the necessary tools to exploring the emergent properties linked to these agents and their activities, establishing some alternatives in adapting to climate change, when these practices are available. In other case ABMs are utilised as instruments for providing insight of some realised behaviours, searching from their motivation.

In Limpopo, South Africa for example seasonal climate outlooks provide one tool to help decision-makers allocate resources in anticipation of poor, fair or good seasons. The “Climate Outlooks and Agent-Based Simulation of Adaptation in South Africa” project investigated whether individuals, who adapt gradually to annual climate variability, are better equipped to respond to longer-term climate variability and change in a sustainable manner (Bharwani and others, 2005).

In the Upper Guadiana Basin, Spain, an ABM investigate the history of irrigated agriculture, in order to learn about the influence of farmers' characteristics on land-use change and associated groundwater over-use, suggesting that risk aversion and path dependency are insufficient to explain the shift between alternative cultivations. This research generally demonstrates that Agent-Based Models can be useful tools to enhance such an understanding even in situation of scarce and uncertainty that often is present in resource-use problems (Holts and Pahl-Wostl, 2011).

In the Argentine Pampas, one of the main agricultural areas in the world, recently has undergone significant changes in land use and structural characteristics of agricultural production systems. Concerns about the environmental and societal impacts of the changes motivated development of an Agent-Based Model to gain insight on processes underlying recent observed patterns (Bert et al. 2011).

In northern Thailand instead an ABM was modelled for ex ante assessment of agricultural innovations, to study in that manner the potential of different new innovations to increase some culture profitability (Schreinemachers et al., 2010).

After have provided also these few general examples about studies in agricultural field

that rely on ABM for their development, it is now evident the fact that this methodology have the capability to consider an indeterminate scale of factors, events and agents. Therefore Agent-Based Modelling confirms its importance an flexibility in being one of the more suitable way to approach as well the challenge of adaptation to climate change as other numerous problem under analysis.

After have presented ABM in general, now our focus shift into a more specific case study analysis. We will treat an Agent-Based Model for the Venice Lagoon Watershed that has already been consolidated in its agronomic conceptual view and we try, through this work, to modelled the actual conceptual framework in a way to obtain in future implementations some more results in terms of economic relapses and connected adaptation practices.

## **CHAPTER 5**

### **A POSSIBLE IMPLEMENTATION FOR THE VENICE LAGOON WATERSHED CASE STUDY**

To well understand the implications of ABMs in a socio-ecological context, we propose in this chapter a personal implementation for a specific Agent-Based Model by Stefano Balbi et al. to be presented at “2012 International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet” in Leipzig, Germany.

In the study by Balbi et al. (2012) an agent-based model was developed to explore how farmers’ decisions affect future water consumption in the VLW (Venice Lagoon Watershed). Modifying some assumption and some procedures, and introducing some new tools, we aim to amplify the vision of this ABM, extending its implication also in an economic perspective, remaining however focused in adaptation to climate variability.

The model considered is a conceptual model, based on Unified Model Language (UML) methodology. The UML is a method that belongs to the computer science tradition and is probably the most effective methods, preceding the coding phase, which can guarantee the full replicability of the model. Using the UML we can formalise in diagrams all the details, providing an efficient method in which to operate as well as an higher degree from the capability point of view.

#### **5.1 The VLW Model**

The following presentation of the “base” model is given by Balbi et al. “Future Dynamics of Irrigation Water Demand in the Farming Landscape of the Venice Lagoon Watershed under the Pressure of Climate Change” paper, that describes the conceptual model, following the ODD+D protocol<sup>37</sup>, a method that can allow to describe human decisions in

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<sup>37</sup> This concept expand and refine the ‘ODD’ (Overview, Design Concepts, and Details) protocol to establish a standard to describe ABMs which includes human decision making (ODD+D) too.

### Agent-Based Social-Ecological Models.

Basically the work is consistent with the idea that irrigation water management for higher agricultural productivity is a challenging task and it requires complex decision making tools that involves farmers and other stakeholders behaviours. An agent-based model can offer an exciting opportunity to model heterogeneous economic behaviour and policy responses from the farmers' viewpoint. In according to this, climate services can provide important tools to help decision-makers allocate resources in anticipation of poor, fair or good seasons. Exploring climatic services and incorporating farmers' behaviour that affect crop yields, an agent-based social simulation can provide a useful tool for adaptation decision making in the context of climate change. In order to do this, the model provide a tool based on soil water balance of FAO-56 procedure as proposed in Allen et al. 1998.

The aim of the model is to investigate how farmers' decisions, in terms of crop and irrigation management affect future irrigation water demand, under the pressure of climate change incorporating available and possible future climatic services. The focus is in particular on how certain decisions, supported by climatic services can cushion against droughts.

Ideally, incorporating available climatic services, the model is programmed to investigate farmers' decision making process and the consequent future irrigation water demand for the period 2015 to 2030.

The model consists of eight main entities: farmer, water infrastructure system, irrigation system, grid cell (patch), soil, crop, market and climate. All the mentioned entities are presented in the unified modelling language (UML) class diagram, as already said.

These entities are represented in a class diagram that provides a representation about the system modelled. Each box contains three areas that express respectively (from top side): the name of the state entity, the list of variables included in each subsystem and finally the way in which these variables relate, or better the actions in which the variables are present.



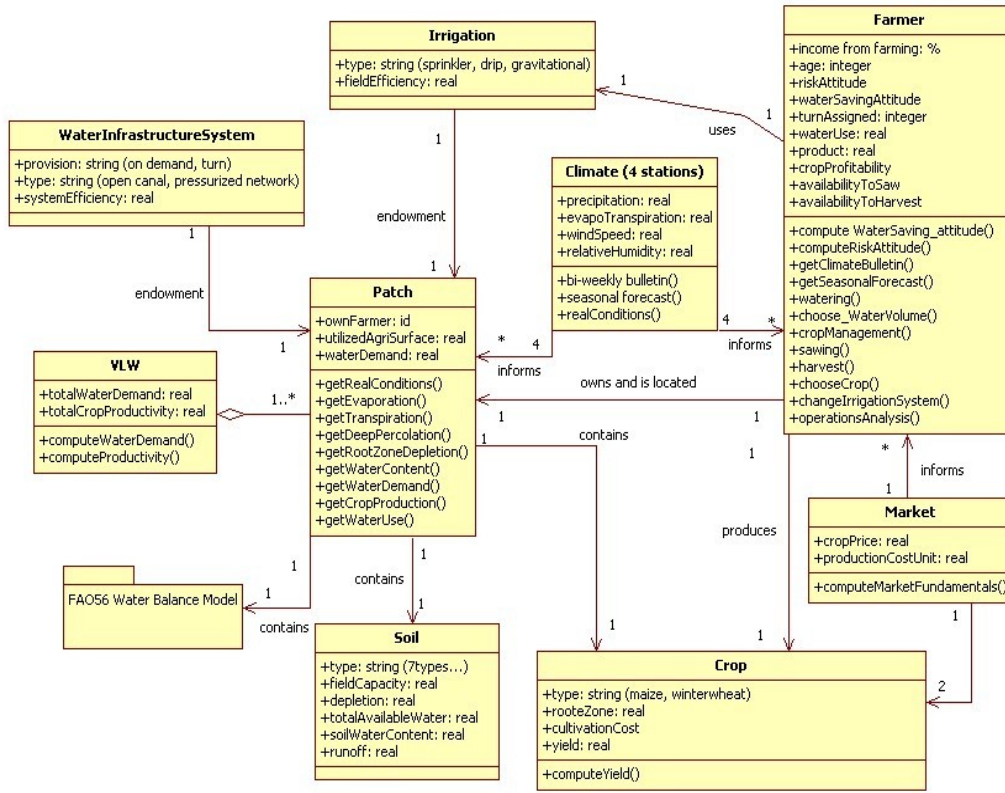


Figure 9 constitutes the UML class diagram for the original model.

Source: Balbi et al. (2012).

The model's entities are described as follows, directly reporting from Balbi's paper in a way to give the rights technical considerations, that are the basis for our future reasoning about the model implementation.

“Farmer’s irrigation behaviour plays a crucial role for the sustainability of crop productions and water consumption; they are human agents with given risk and water saving attitudes, affecting the irrigation and crop management decisions. Risk attitude depends on age and the share of income determined by farming. Attitude towards water depends on the crop profitability and the share of income determined by farming.

Water infrastructure system is represented by the provision typology and the related system efficiency. Two types of provisions are available: (1) pressurized system with water on demand, and (2) open canal with water on turn.

Irrigation system is characterized by type and related field efficiency. For the VLW, three types are considered: (1) gravitational, (2) sprinkler, and (3) drip.

Patch is represented by utilized agricultural surface owned by single farmer that contain soil and crop. In the current prototype model landscape, representing the VLW, is segmented into 2,038 grid cells of 1 km<sup>2</sup> each. Overall 74.3% of total area is agricultural, and approximately 90% of it is Utilised Agricultural Area (UAA).

The soil entity is characterized by type, field capacity, depletion, total available water, soil water content and run-off. This model implements the logic of the FAO-56 water balance model at the patch level.

Crop is represented by type, root zone depth, and yield. Two types of crops are considered in this prototype: winter wheat and maize. The first is chosen to represent rainfed crops with cycles from autumn to late spring and limited climate sensitivity, while the latter is the typical irrigated crop with spring to autumn cycle and high water consumption and sensitivity. The market is described in terms of crop prices and production costs. The climate entity is represented by four climatic stations characterized with climatic variables (i.e. precipitation, evapo-transpiration, wind speed and relative humidity) available as simulated at daily steps by regional climate models, from which climate services information are derived (i.e. bi-weekly bulletin and seasonal forecasting). The model runs with daily time steps over a period of 15 years (2015-2029). For simplicity in the current version it is assumed that there is a one to one correspondence among the main entities, meaning one patch, one farmer, one crop per year, etc.<sup>38</sup>.

As regarding the model process, it is divided in two levels: tactical and strategic.

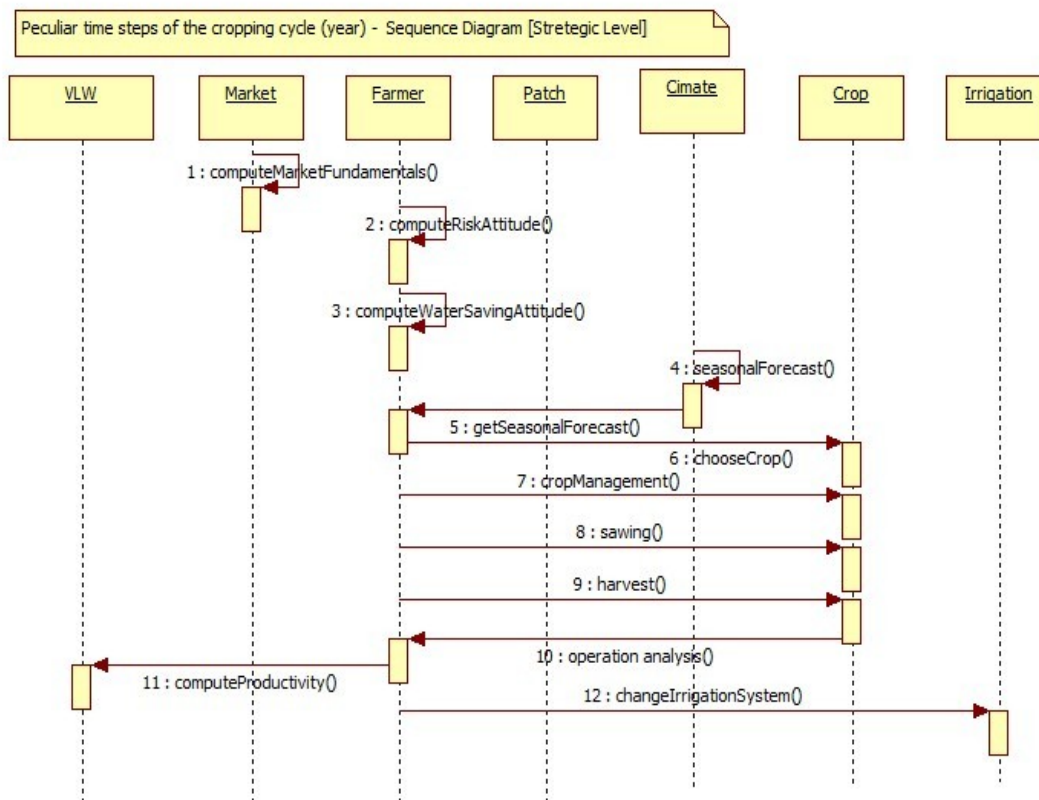
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<sup>38</sup> Source: Future Dynamics of Irrigation Water Demand in the Farming Landscape of the Venice Lagoon Watershed under the Pressure of Climate Change, Balbi et al., (2012).

“The tactical level includes those operations which are carried out on a daily basis and are related to the decision about watering by farmers (i.e. “getClimateBulletin”, “watering”, “chooseWaterVolume” operations) and to the updating of the climatic data and the water balance model at the patch level. The choice of watering (i.e. yes/no) depends on farmer’s notion of the soil water status and own water saving attitude. For farmers who have water on demand the amount of water is influenced by the bi-weekly bulletin. Conversely, farmers who have water on turn do not consider the expected precipitation but they take into account the possibility of saving energy on the basis of the irrigation system in place. The strategic level includes those operations which take place only at certain moments of the year and represent the core of the farmers’ behaviour (see the UML sequence diagram). At the beginning of the year the market computes the market fundamentals. Two options are available: (a) fixed parameters updated at January 2012, and (b) dynamic parameters based on the range of values over the year 2011 [ISMEA 2012]. The seasonal forecast, which contains information about the average distance from the reference values for forecasted precipitation for the crops critical periods, is produced and delivered. At this point, farmers can choose the preferred crop for that year, according to their risk attitude. This implies different sowing and harvesting schedules. Maize is sown in March and harvested in November but winter wheat is sown in October and harvested in June. For maize, June and July are the critical months as these are the flowering periods and for winter wheat, September and October are the critical periods (sowing time). After harvesting, farmers analyse their performance in terms of crop productivity and water use. At the end of the year they can plan to change their irrigation system”<sup>39</sup>. Following the sequence diagram about strategical actions are presented.

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<sup>39</sup> Source: Future Dynamics of Irrigation Water Demand in the Farming Landscape of the Venice Lagoon Watershed under the Pressure of Climate Change, Balbi et al., (2012).



**Figure 10** represents the UML sequence diagram for strategic actions.

Source: Balbi et al. (2012).

About the theoretical and empirical background constituting the basis for the design phase of the model, the following evidences are exposed in the submitted paper.

“Climate change impacts on the VLW are expected to be particularly relevant for agriculture. Farmer’s irrigation behaviour will increasingly play a crucial role for the sustainability of crop productions and water consumption. Innovative approaches may require substantial private and public investment. In particular it is interesting to investigate the degree of autonomous adaptive capacity given the infrastructure and the climatic services in place, and how planned adaptation could enhance it (e.g. by changing infrastructure and/or increasing the quality of climate services). Currently the water

infrastructure in the VLW is almost entirely based on open canals and 93% of the total area is served by sprinkler irrigation systems [INEA 2009]. Different configurations are adopted in the preliminary version of the model for the purpose of testing heterogeneous conditions, while taking in consideration that certain irrigation systems are more suitable with specific water infrastructures.

At the same time the crop choice is simplified into a dichotomous choice in order clearly distinguish between rainfed and irrigated cultivations. Further, when dynamic market fundamentals are chosen it is assumed that winter wheat renders more stable revenues, while maize may produce higher incomes with low probabilities.

The farmers' decision model largely depends on their classification in terms of risk and water saving attitude. The notion of age and share of income (i.e. off-farm income) affecting risk attitude is quite consolidated in the literature. Conversely there is scarce information on water saving attitude, also because irrigation water cost represents usually less than 3% of total production costs [INEA 2007]. Thus, it is assumed that water saving is pursued only when the crop profitability shrinks as a consequence of saving on other cost elements, such as energy (i.e. pumps needed with sprinkler irrigation systems), and when the farmer income largely relies on farming activities"<sup>40</sup>.

Having established the logical guide principles and the empirical findings standing on the basis of the paper, the core of the model consists in describing "Individual Decision Making".

At this purpose, "in order to inform the farmers about future climatic conditions, two types of climatic services are made available: (1) the bi-weekly agro-meteorological bulletin, and (2) the seasonal forecasts. Using these climatic services, farming agents take adaptation decisions on the basis of their own risk and water saving attitudes.

Tactical adaptation measures concern irrigation water management, while strategic

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<sup>40</sup> Source: Future Dynamics of Irrigation Water Demand in the Farming Landscape of the Venice Lagoon Watershed under the Pressure of Climate Change, Balbi et al., (2012).

decisions concern the crop choice and the change of the irrigation system.

The bi-weekly bulletin provides the farmers with information about the forecasted cumulative precipitation of the next three days. The sequence of events is predetermined in the simulated weather records, but the quality of forecasts can be degraded, thus moving from a situation of perfect knowledge to bad quality information.

Risk taker farmers with water on demand will decide to irrigate only when the readily available water shrinks to zero. Risk averse farmers with water on demand will water before this stress threshold, and in particular, when the readily available water is inferior to 50% of its maximum point. Both these typologies of farmers will water up to field capacity, taking into account the expected precipitation.

Farmers with water on turn will water depending on irrigation systems. In case of gravitational and drip systems they will irrigate when water content is below 95% of saturation up to saturation. In case of sprinkler systems they will irrigate when water content is below the field capacity up to field capacity. Both these typologies of farmers do not consider the expected precipitation.

The seasonal forecast affects the strategic choice of crops. If seasonal forecast for maize is critical, risk averse farmers who previously harvested maize will switch to winter wheat. Similarly, if the seasonal forecast for winter wheat is critical, risk averse farmers who previously harvested winter wheat will switch to maize.

Further, farmers can choose to change the irrigation system on the basis of the existing infrastructure, in order to improve the combined system and field efficiency.

It is assumed that gravitational is the first best choice when the infrastructure is open canal, while sprinkler is the target when the infrastructure is pressurized system. In few cases farmers will opt for drip irrigation systems. Probability rules affect the year in which the eligible farmers can take this decision. There is a time lag of two years between the decision and the new system in place<sup>41</sup>.

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41 Source: Future Dynamics of Irrigation Water Demand in the Farming Landscape of the Venice Lagoon

To complete to provide the necessary tools, Balbi's work some other useful information about the modelled system characterization.

In particular began by noting that, in this first model version, no learning processes are included in decisions. However, it is planned to include memory for example about forecasts quality or some individual processes that could affect farmer's choices.

Farmers endogenously know, through the FAO-56 model, the water balance and the water volume delivered to their field, and consequently they know the crop yield. They also exogenously perceive information on climatic parameters and about their infrastructure systems, at the patch level.

There is no interactions among farmers but each farmer interact with is own patch in which information records are stored. Furthermore the water infrastructure system considered is collectively shared.

Climatic conditions are predicted by the means of climate services; these predictions could be erroneous because of the degradation parameters applied to simulated data representing the A1B IPCC climatic scenario, considered in this model as the reference climate state for simulating future climatic patterns.

Farmers are considered heterogeneous in terms of risk and water saving attitudes because of their different age, relative income from farming and crop profitability. Heterogeneity also involves other entities of the model like crop types alternation, soil profiles, weather stations of reference, types of irrigation systems, types of water infrastructure systems.

Sowing and harvesting periods of maize and winter wheat are randomly determined, considering the fact that there are not sown or harvested on the same day of each year. Stochasticity is also included in the choice of changing the irrigation system in order to avoid all the farmers with the same configuration to act at once. Moreover, market fundamentals tools are considered stochastic too; in fact price for winter wheat is

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Watershed under the Pressure of Climate Change, Balbi et al., (2012).

normally distributed while maize refers to a long tailed Poisson distribution concerning its price.

Ideally at the end of each year (from 2015 to 2029), annual water demand and annual crop yield are collected for each patch, which is then aggregated at VLW level. The aim is to compare future dynamics about water demand and crop yield for the involved area, under different model configurations regarding: (1) initialization, (2) water infrastructure in place, (3) climate service quality.

About the initialization data, “the model is initialized with 1,514 farmers, one per agricultural grid cell. Farmers’ age and share of income from farming are distributed according to regional statistics of VLW. For simplicity the utilized agricultural surface is set at 90% of patch area in every cultivated patch.

Differently from current real conditions (99% open canal) it is assumed an initial distribution of 50% per type of water infrastructure systems. The probability distribution of irrigation systems depends on the infrastructure in place: 10% gravitational, 60% sprinkler, 30% drip, for pressurized system, and 60%, 30%, 10% for open canal”<sup>42</sup>.

## ***5.2 Emphasizing economic perspective and emergent properties in VLW Model***

The implementation of the model we will present in the following lines is based on the idea that economic tools could interact with the entities already present in the model, providing interesting socio-ecological feedbacks.

In Venice Lagoon Watershed model the economic perspective is marginal, providing only few economical signals from the market in terms of prices and costs connected to the relative chosen crop.

In this way the resultant of the model are purely agronomic, while other socio-economic

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<sup>42</sup> Source: Future Dynamics of Irrigation Water Demand in the Farming Landscape of the Venice Lagoon Watershed under the Pressure of Climate Change, Balbi et al., (2012).



factors are not take into account at all, as the effects they can produce in the studied system.

Nevertheless the model, like the generality of ABMs, is flexible and inclined to various type of changes. In this manner we are enabled to explore some “undiscovered” feedbacks hidden in the system by introducing some concepts and functions, that could allow us to analyse different relationships among the actors involved and show others potentials deriving from the model.

Obviously the presented implementation has not to be considered the only or the better one. With this work we aim to explore a possible development path starting from the original conceptual model. So the work is arranged to continuous and multiple revisions, depending only on the logical background that support each analysis.

#### *5.2.1 The “New” Conceptual Model: Entities, Variables, and Scales*

This “new version” of VLW model aims to include some new variables and changes some others in a way to modify some of the assumptions standing on the basis of the conceptual UML original version by Balbi et al.

With respect to the 8 entities included in the conceptual model, they are the same as the original one. The changes occurred concerning in particular the composition of these entities, in terms of variables and actions contained within them.

Thus, in our work the changes in the structure of the model regard in particular farmers' income entity and its composition. The importance of that variable for the model is given by the multiplicity of its influences procured in the entire system. We analyse these reports in details in the next pages.

We reiterate now the economic perspective, that is which we aim to improve in our model's development.

From that point of view, we can consider the farmer as an artisan entrepreneur, in

accordance to M. Florio, (2010). This thought is important in given the right idea concerning income configuration in that context. In its archetype, the craftsman is an employee who owns its production factors, a modest fixed capital assets, in any case sufficient, in combination with the application of direct labour (his labour), to allow him to produce on a small scale. At the same manner we can interpret the farmer in our model, as an agent that own its production factors, given by crops and physical capital assets, the irrigation system. For that type of agent, the entity of income, deriving from labour, capital or profit is relatively confused and is difficult to discern, properly because of the intrinsic character of the described agent. That's why it is difficult for these types of activities, like the agricultural one, to apply the “traditional theory of enterprise”.

Therefore in the model income is treated as an unique entity. The only, but fundamental differentiation is to divide income into farm-income and off-farm income. At this purpose, it is well known that farmers' income is composed by a first part (central in our model) arising from farm activity, while a second part depends from “external” earnings.

Like the original VLW model, farmers' income is treated as a percentage of the total income (assumed normalised to 100); the difference consists in its dynamic. In the version proposed by Balbi et al. income follows a casual pattern (a very simplified assumption), while modifying income concept we aim to give it a more complex dynamic, based on the evolution of three key variables: *physical capital*, *savings* and *indemnity*.

In this manner the variable *farm-income* in our model co-evolve with the three variables cited, each one governed by some theoretical background that we will treat in details in the following lines.

Meanwhile, in few words we can say that the *physical capital* variable is defined according to the logic of Klaus Hasselmann' s contributes to MADIAM model<sup>43</sup>, and includes itself the

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43 References: Klaus Hasselmann, Dmitry V. Kovalevsky. Simulating animal spirits in actor-based environmental models. Elsevier, Environmental Modelling and Software. doi:10.1016/j.envsoft.2012.04.007. (2012). A Multi-Actor Dynamic Integrate Assessment Model (MADIAM) of induced Technological Change and Sustainable Economic Growth; Michael Weber, Volker Barth, Klaus Hasselmann.

concepts of technological and human capacity; in particular in VLW model it represents the efficiency of irrigation structure. *Savings* instead are included in the model as a resource through which farmers may begin to insure their yield, following the logic of “Multiple-peril Crop Insurance”<sup>44</sup> in such a way that a minimum yield could be “saved” if farmers undertake some type of policies. *Physical capital* and *savings* depends both on farmers' decisions concerning how to invest the profit deriving from agricultural activity. The profit variable is crucial being the resource to allocate alternatively in irrigation structure improvements or in financing insurance practices. The amount of profits is determined, like the original VLW model, by farmers' crop production, deriving from FAO model that compute the amount of yield for specified climatic conditions.

The investment strategy depends in turn on farmers' risk-aversion following the basis of the original conceptual model.

Finally the variable “indemnity” is the entity representing the compensation deriving from insurance practices that we assume strictly depends from savings.

The evolution of these factors contribute to establish the weight of farm-income relative to total income, this rate increases when the growth rate of farm-income are higher relative to the appreciation rate of off-firm income, the entities that farmer allocate in other activity (for example in banking services) and that grow at a constant interest rate.

As already said, for our conceptual model it's important to mention the implications regarding income because they condition farmers' behaviours in terms of calculation of risk and water saving attitude. An other potential side effect could occur for example by the impact of physical capital growth represented in terms of efficiency of the irrigated structure, as a constraint for *changing irrigation* actions to be taken by farmers.

About scales, all the cited variables, representing income composition should be expressed in monetary terms, in a way to be analytically adequate and therefore

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44 References: Agricultural Insurance, Ramiro Iturrioz, Primer Series on Insurance Issue 12, November 2009; Relative to insurance features visit: [www.worldbank.org/nbfi](http://www.worldbank.org/nbfi).

comparable.

We have now described the main changes we propose at the most general level.

This considerations can be seen in the following class diagram, in which the new variables and actions are included. It represents the model from the system perspective.

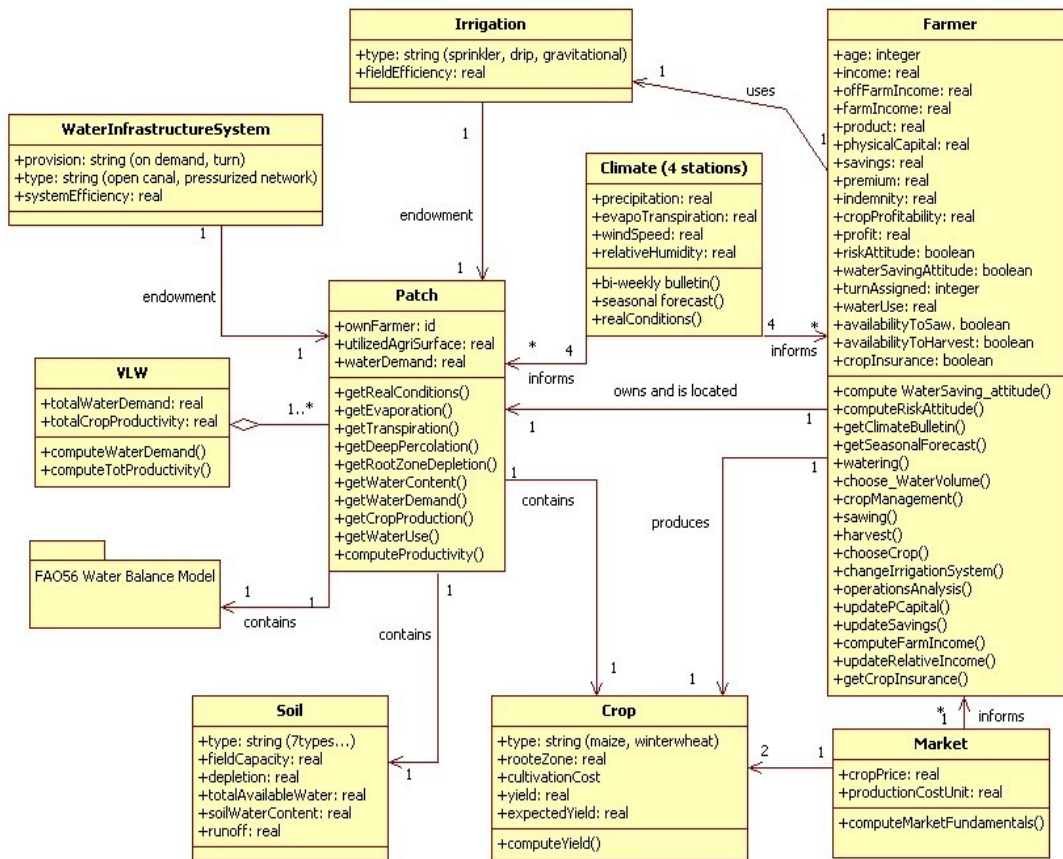
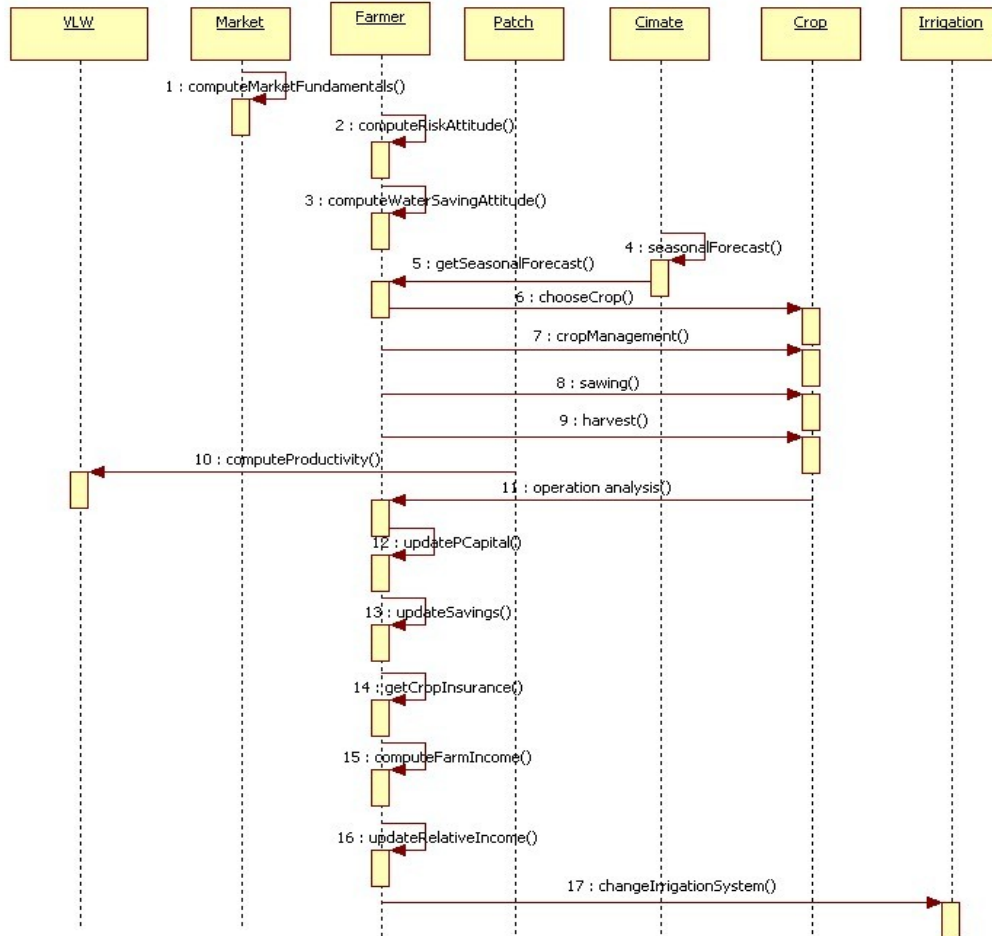


Figure 11 shows the UML class diagram of the “new” model.

### 5.2.2 Processes and Individual Decision Making

The changes that have been developed fit into the model in a strategic way, modifying the original strategic sequence diagram that describe the sequence in which operations take place. As already said the strategical behaviour of the system concerns operations that

take place only at certain moments, in our example each year. In other words the diagram below is a representation about medium/long term decisions.



**Figure 12** represents UML sequence diagram, in which new actions are included.

Now we will present one by one the main “new” actions of the model, or the modified ones; in particular we are interested in how these actions and relative relationships take place, and how they could affect the logic of the system, providing some new emergent properties<sup>45</sup>.

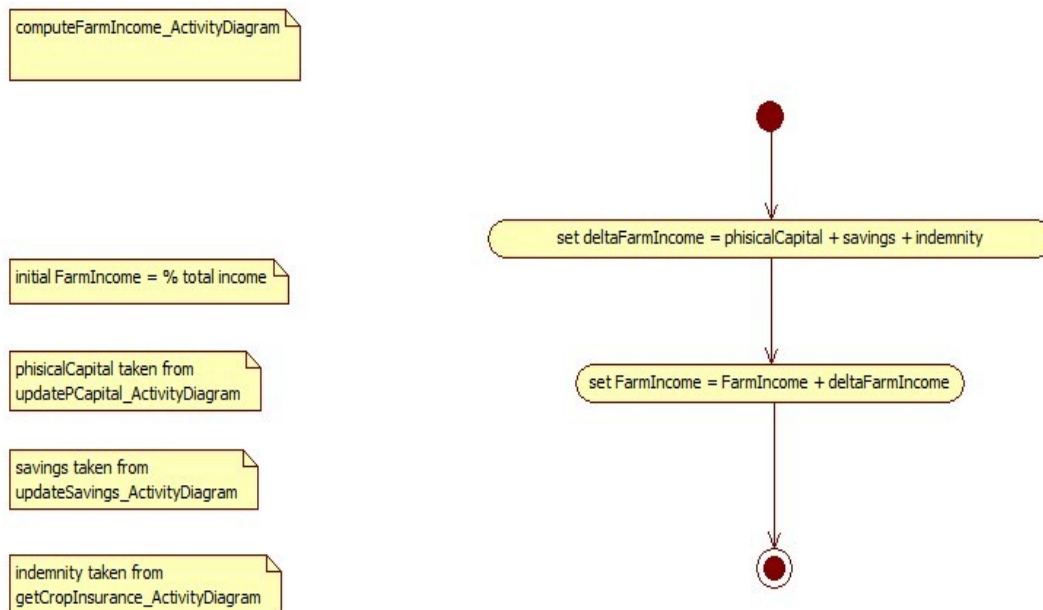
We start the description about system activities from the entity that is mainly affected by

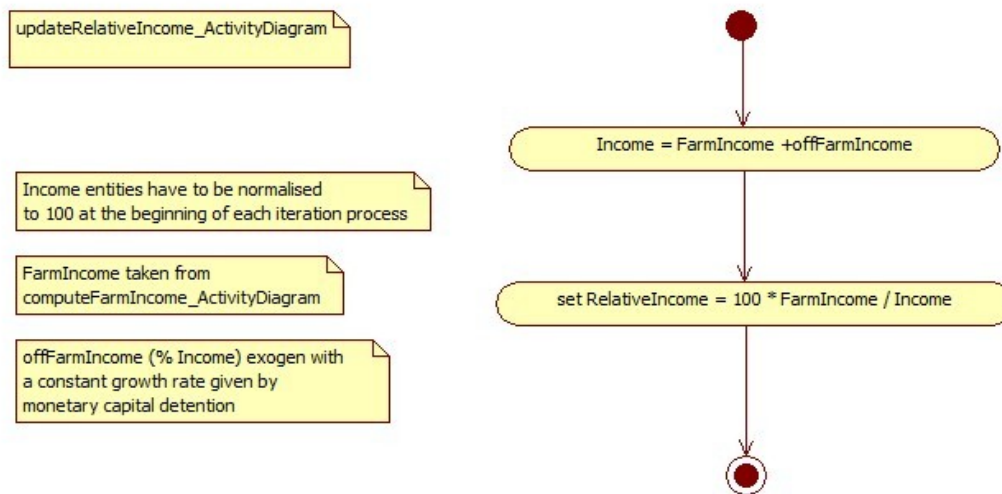
<sup>45</sup> About emergent properties see chapter 4 about ABM.

our conjectures, income in its different form: total, farm and off-farm.

The principal change in the conceptual model regards basically the structure of farm income. We assume that income from farming linearly depends from three main variables: physical capital, savings and indemnity. We decided to consider specifically these variables based on the fact that physical capital and insurance are issues that could well relate with the logical background of the original VLW model and, in that manner, are able to provide some interesting findings interacting with the system modelled.

In our study we use for simplicity a linear function, as shown in the following activity diagram, that describes the interdependences between farm income and the production factors.

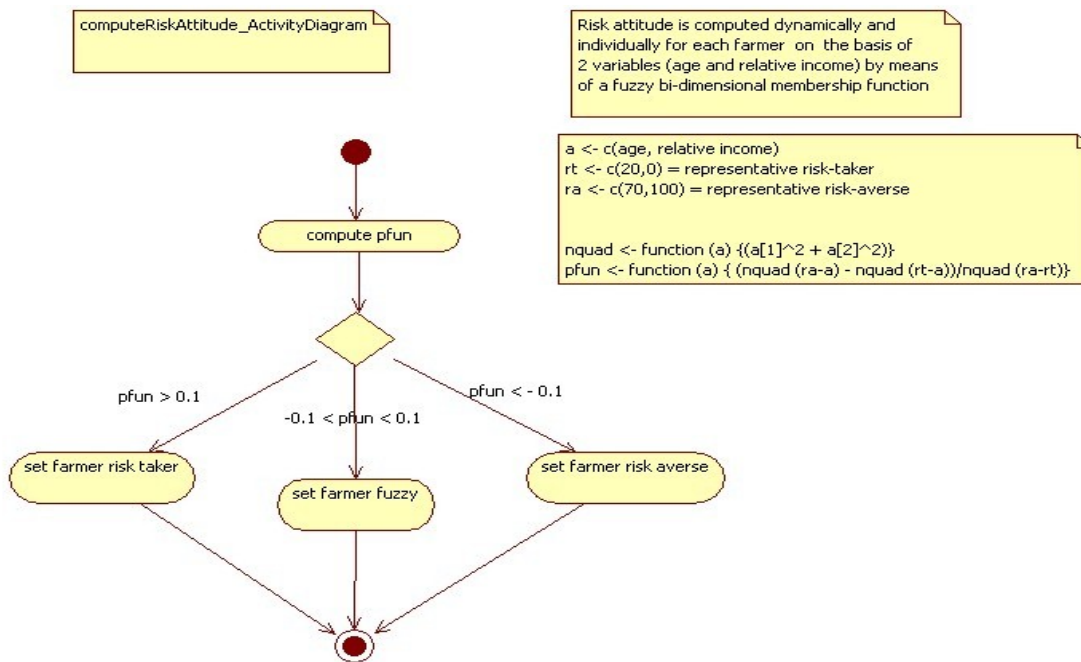
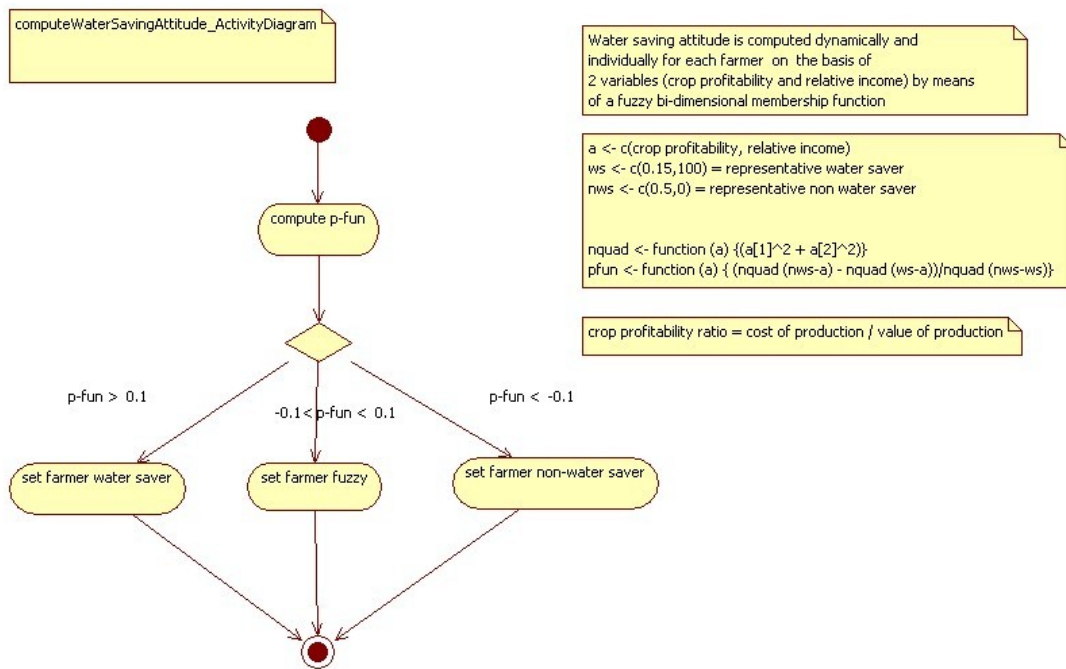




**Figures 13 and 14** represent UML activity diagrams for the calculation of the farm-income entity and the relative income entity.

The basic idea is that the initial value of farm income could be assumed as a percentage of total income, in a way to have a look to how this ratio (relative income) can evolve over time. When the growth rate of farm income is greater than those of off-farm (assumed constant), the relative income becomes higher.

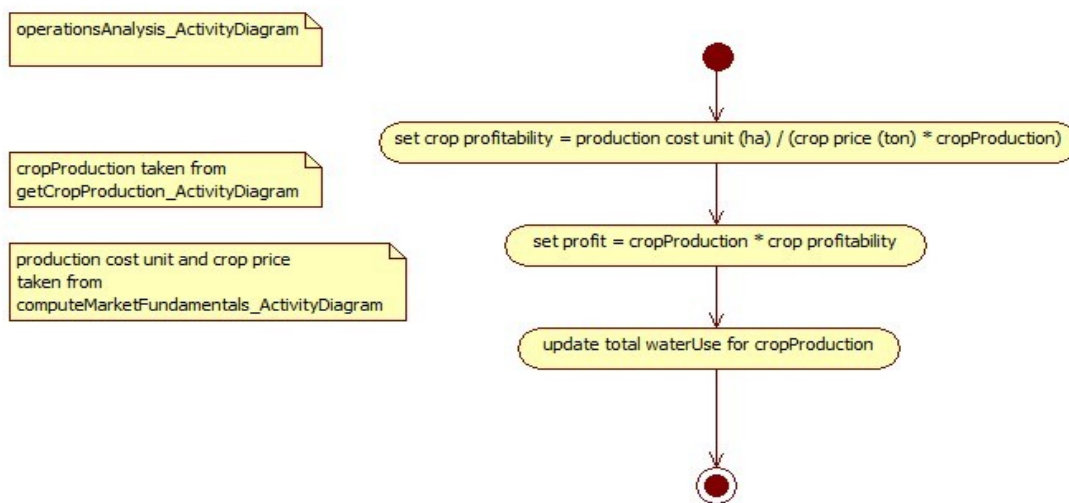
This date is not useful itself, but becomes important because of the connection between relative income and farmers' behaviour in terms of computing risk attitude and water saving attitude. In fact these behaviours, as represented in the following activity diagrams, depends, in addition to other variables (age and crop profitability), properly from the income deriving from farming, computed as the relative income. The graphs that follow give the representation of these actions. They differ from the original model only in the amount of variables involved. Thus, the logic about relationships and calculation methodology aren't modified at all.



**Figures 15 and 16** are the representation in UML about farmer's attitude towards water saving and risk variables, following the logic from Balbi et al. 2012 about the computation of these behaviours.



Besides relative income entity, an other important variable, related to water saving attitude decision-making is constituted by crop profitability. Crop profitability as in the logic of VLW model, mirrors the shape of the distributions used for prices associated to the relative crops. As said in the presentation of the original model, having a look at INEA crop market parameters, we can fix prices for maize along a Poisson distribution, while prices for winter wheat follow a Normal distribution. Costs are instead fixed, with only a stochastic element that provides random variations (+/- 100 euros). Knowing these information, farmers' could determine their profits following the actions pointed out in the next activity diagram.



**Figure 17** provides the UML activity diagram for the determination of crop profitability and the calculation of farmer's profit.

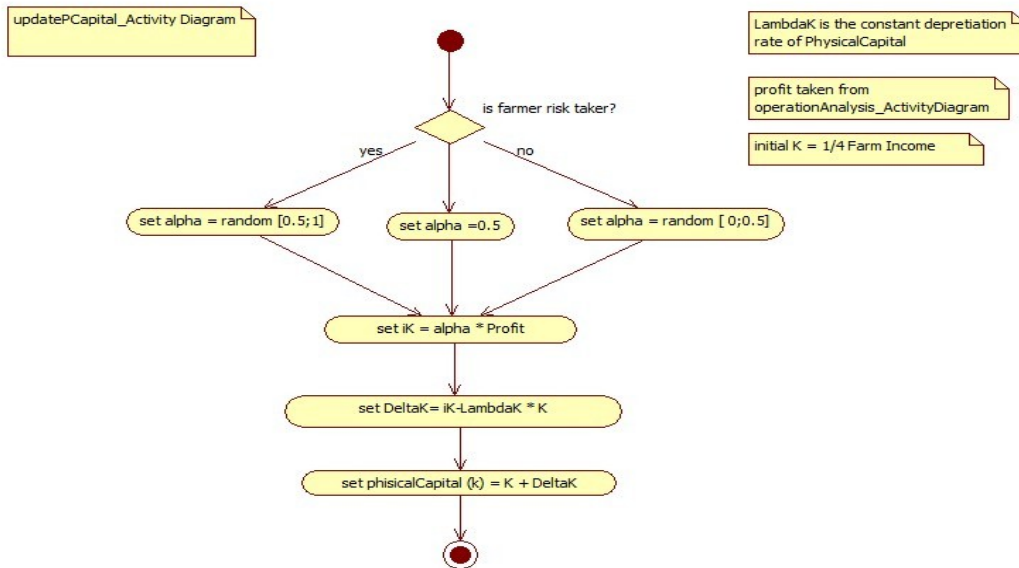
Crop profitability, as we said, it is an important variables because it enters into water saving attitude computation; but it consists also in the parameter that, once have been setted, allow us to compute the effective profit obtained by the farmer. This is, along with income, the other crucial entity for the modified UML model.

The profit determination opens the other crucial issue of the “new” model, linked to the concept of investment choices to be undertaken by farmers.

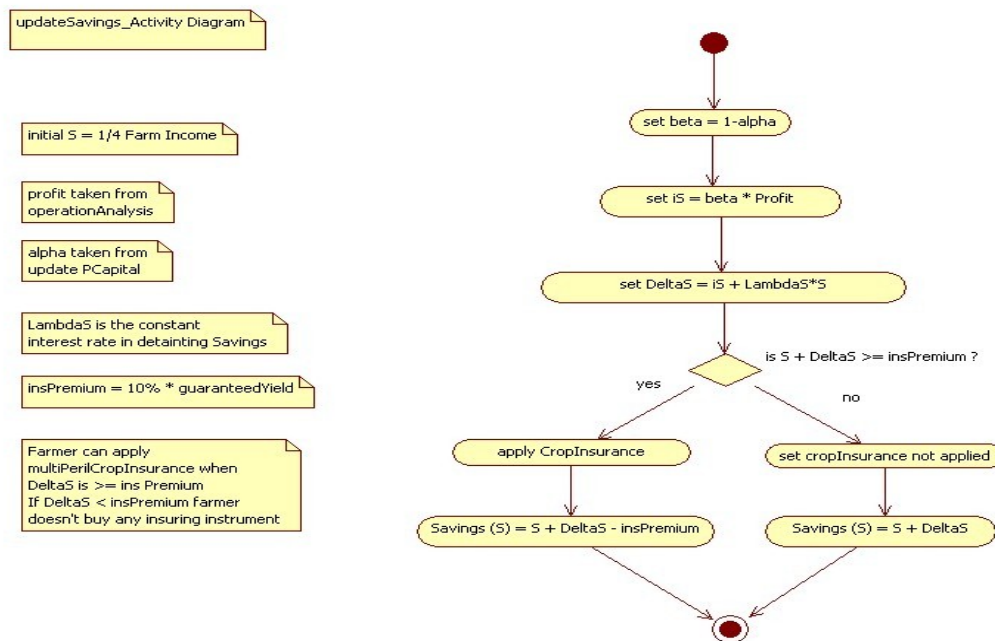
In accordance to K. Hasselmann<sup>46</sup>, economic growth, and consequently the amount of income in which farmers dispose, depends on the way business (our farm activity) chooses to partition its profits through investments; and in particular we assume that farmers alternatively invest their profits in physical capital or savings.

In such a way, the choice about investments affects in different ways the entities corresponding to physical capital and, on the other hand savings, determining the trends of these two factors, whose analytical evolutions are shown in the next activity diagrams.

However, it is important to mention the production variable too, that determines, through the yield calculation, the crop production and so, indirectly, the profit amount or else the total amount that farmer could invest at each time step. At this purpose we remind to the FAO model already cited, that are the method considered in compute the crop yield, step by step.



46 References: Hasselmann K., Kovalevsky Dimitry. Simulating animal spirits in actor-based environmental models. Elsevier, Environmental Modelling and Software. doi:10.1016/j.envsoft.2012.04.007. (2012). A Multi-Actor Dynamic Integrate Assessment Model (MADIAM) of induced Technological Change and Sustainable Economic Growth; Michael Weber, Volker Barth, Klaus Hasselmann.



**Figures 18 and 19** shows UML activity diagrams for the computation, in order, of physical capital and savings.

The last two diagrams presented above (*updatePCapital* and *updateSavings*) involve a dual function; to show the dynamic of each factors on one hand and intrinsically to determine the behaviour concerning investments, rely to risk-attitude, on the other hand.

The importance given to investments in agricultural field, land and water in particular, are highlighted also by FAO institutions<sup>47</sup>, that place investments in land and water as key factors for economic growth, taking in particular the form of agricultural productivity growth, and contributing in that way not only relative to short term benefits, but also with respect to long term welfare.

Together with labour, capital and technology, land and water constitute the aggregate resource base for agricultural production. Judicious and efficient use of these resources underpins sustained and enhanced agricultural productivity and food security. This calls

47 <http://www.fao.org/docrep/005/ac623e/ac623e00.htm#Contents>.

for increased investment in agriculture, and especially in land and water development<sup>48</sup>. Technology can contribute to economic growth by overcoming resource scarcities and by combining products and inputs to optimise output. However, complex, diverse and risk-prone production environments call for adaptive designs and strategies, and investment strategies are the means to undertake these actions taking into account uncertainty connected to climate risk<sup>49</sup>. Farmers are wary of changing traditional farming methods and need exposing to new techniques without their carrying too much risk, and that's way in our model investment choices are dependent from agents' risk aversion. Increased agricultural output will have to come mainly from intensified rather than extensive production as per capita land and water resources diminish. Such increases in productivity will require increased investment in agriculture, and especially in land and water development. Through investments in this field, farmers' aim to ensure a regular and timely supply of water; in this way irrigation could reduce the risk of crop losses from uncertain rainfall and enables production in areas or at times without rainfall. In addition, through its impact on agricultural productivity, irrigation has beneficial effects on rural incomes, rural employment, food security, poverty alleviation and overall growth and development<sup>50</sup>.

Let's describe now *physical capital*, that we could assume initially as a percentage of available farm income; we suppose for the initialisation of the process, that initial physical capital could be equal to  $\frac{1}{4}$  \* *farm income* in our specification.

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48 References: Investing in land and water: the fight against hunger and poverty in the developing Asia; R.B. Singh, Assistant Director, General and Regional Representative for Asia and The Pacific, Food and Agriculture Organization Regional Office for Asia and the Pacific, Bangkok, Thailand .

49 Investment in land and water in the context of the Special Programme on Food Security; J. Poulisse, Senior Economist and J. Thomas, consultant rural development Land and Water Development Division, FAO, Rome.

50 The benefits of investment in land and water; K. Yoshinaga , Director, Land and Water Development Division FAO, Rome.

According to Hasselmann's thought, we can describe the physical capital dynamic through the function  $\Delta K = ik - \lambda k * K$ , in which the variation of physical capital  $K$  is given by  $ik = \alpha * profit$  coefficient, that represent the share of profit resulting from the investment choice, minus the depreciation rate  $\lambda k$  (maintained constant along time) multiplying for the amount of physical capital deriving from the previous time step. Now, the “new” physical capital will be obtained simply adding the variation of the capital entity,  $deltaK$ , to the actual one.

We built a similar procedure for *savings*, whose variation  $\Delta s$  is given by the invested profit's share  $is$  and the appreciation rate for savings  $\lambda s$  (constant) multiplying for the actual amount of savings, that for example could be represented by interests for farmers deriving from investing their savings in banking services. Like the investment in physical capital, the investment in savings are given by a parameter that is a portion  $\beta = 1 - \alpha$  of profit generated by farm production.

The evolution of these variables are strongly linked to decision-making about investments; this choice is in turn conditioned by the farmers relative risk attitude. If farmer turns out to be risk taker, the result is that higher share of profit is allocated into investment in physical capital, improving in that manner the irrigation structure owned by the farmer; indirectly this type of investment affect production and farmer income. A risk averse farmer instead will prefer to invest in savings, that allow farmer agents to own the necessary capitals to apply insurance practices in a way to protect yield against variability due to climate perturbations.

Savings are therefore the entity that could provide to allocate monetary resources, expressed in the model as shares of obtained profits, for insurance practices. In particular we assume that, if farmers have enough savings to pay for insure their yield, then they decided to pay insurance premium (that will decrease the total savings available for the future); if the contrary occurs, farmers don't hold the resources for insure their crop yield, and so they cannot protect themselves from climate risk.

### *5.2.3 Considerations about the Model's Adaptive Capacity*

After having analysed the effect of investment choices and, together, the logic standing behind the main actions driving the evolution of farm income, we now focus on others important implications, that result from the proposed model in the potential adaptation practices against climatic risk.

These implications about possible adaptation strategies constitute the goal we had in charge at the beginning of these implementation of the model. Part of the logic concerning these strategies were already be discussed, but they will be now replied trying to explain conceptually the bases of these behaviours.

Relative to agricultural field, several adaptation practices could be considered.

Agricultural adaptation options are grouped according to four main categories that are not mutually exclusive: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management. The typology is based on the scale at which adaptations are undertaken and at which the stakeholders are involved. The first two categories are principally the responsibility of public agencies and agri-business, and adaptations included in these categories might be thought of as system-wide or macro-scale. Categories 3 and 4 mainly involve farm-level decision-making by producers. Of course, the categories are often interdependent (Smit and Skinner, 2002).

In the VLW model we consider, farmer operations concern micro-system, so the adaptation options we can consider are linked in particular to farm practices.

The two possible adaptation options deduced from the conceptual model are linked to the farmer's behaviour regarding the two possible ways in which profits could be reinvested. According to Smit and Skinner (2002), the considered adaptation options derive from the category of "farm financial management", involving investment practices, but are also

connected into the third class of operations, involving technological changes in terms of improvements in the irrigation structure.

The category of farm financial adaptation options cover also crop insurance practices, that reduce income loss as a result of reduced crop yields from droughts, floods and other climate-related events. Purchasing insurance entails financial decision-making aimed at stabilizing income from crop production in light of climate change risks.

In summary, in VLW model the considered alternatives correspond to the choices about to insure farmer's crop yield by crop insurance practices, or contrary to improve the efficiency of physical capital, represented in the model by the irrigation structure, investing in that.

Starting from the insurance practice, we based our reasoning on “multiple peril crop insurance”, a specific type of insurance based on crop yield that provides insurance against all perils that affect production unless specific perils have been explicitly excluded in the contract of insurance. Under this type of insurance, the sum insured is defined in terms of the expected yield to the producer. Cover is normally set in the range of 50 to 70 percent of the expected yield. We prudently affirm that this cover could assume in our model a level of 50%, corresponding to the yield guaranteed by indemnity deriving from insurance practice<sup>51</sup>.

Risk management is to date considered a crucial issue for societies, in particular if the sector involved is agriculture and its multi-functionality, as in our case study. Many institutions like INEA are interesting in climate risk management, concentrating efforts especially in insurance mechanisms and practices.

Insurance practices result to be in absolute the most suitable instrument for transferring climate risk, by paying the insurance premium to the insurer. At global level this is probably the methods most commonly used. But it present also an high degree of

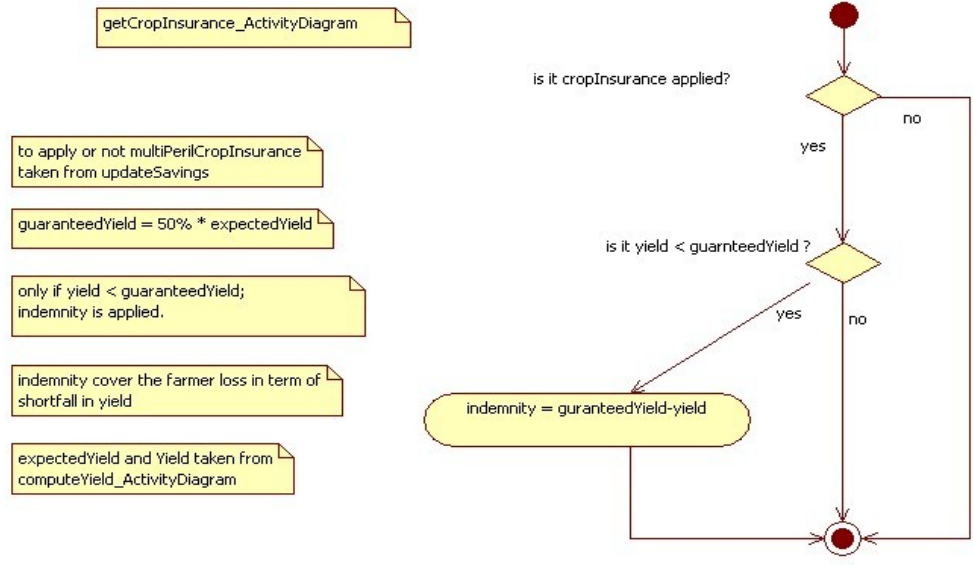
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51 References: Agricultural Insurance, Ramiro Iturrioz, Primer Series on Insurance Issue 12, November 2009; Relative to insurance features visit: [www.worldbank.org/nbfi](http://www.worldbank.org/nbfi).

differentiation, depending from what and how to insure, and from structural differences, from example within different countries, each one based on different policies and insurance methodologies.

Confirming the high importance of this practices, in the case study we propose we have to adapt the chosen insurance concept to the model structure; in this manner we introduce a logic for undertake this type of policy, even if its real application is quite different.

As we can see in the diagram below, when farmer in our example own the resources to destine to insurance practices, the *CropInsurance* mechanism will take place. The activity diagram describes the logical background of insurance application into the model context. It is important to notice that the “multi-peril crop insurance” proposed in our model is a simplified version compared to the entire logic that governs this instrument. In particular future market prices are not considered, basing our calculation about compensation only in terms of yield, in particular computing the difference between actual yield and the guaranteed one.



**Figure 20** describes the activity diagram about insurance mechanism in UML.



The simplified insurance practice presented in this work, is based on the fact that a certain level of yield could be assured by the farmer, allocating a share of his profit first to savings, and then, paying the correspondent premium, to crop yield insurance. The premium to pay is considered as a percentage of the guaranteed yield, and normally covers a range between 5 and 20 percent of the guaranteed yield (R. Iturrioz, The World Bank, 2009).

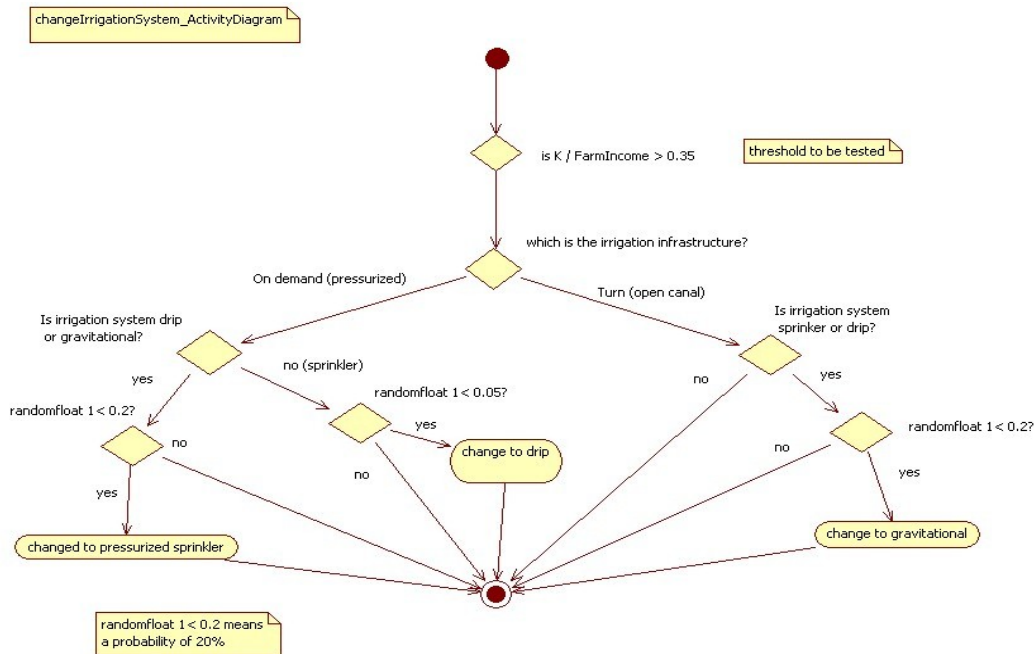
Following these bases, when crop yield falls compared to the guaranteed yield level, indemnity mechanism enter into force, compensating the losses until this insured level.

It is clear that insurance, if correctly applied, could be a positive way to smooth the negative effects of climate change on crop yield. So, it could theoretically represents an efficient adaptation option against climate change in the considered model as well as for the entire agricultural system.

We note again how the insurance logic we have told about was taken in exam because of its consistency with the conceptual model and the logic of the proposed implementation. Several insurance practices are available nowadays and numerous other assumptions and observations could be made, also referring to this model.

The other important implication in terms of adaptation option regards the decision about to invest farmer's profit into irrigation system efficiency.

The activity diagram showing this possibility is the next, presented below.



**Figure 21** represents UML activity diagram for changing irrigation system.

Structure taken from Balbi et al., (2012).

The diagram illustrates how farmer's behaviour could indirectly affect the actions in changing the infrastructure system.

Basically the scheme of this activity follows the logic from Balbi's model that guides the mechanism to change irrigation system in a purely deterministic way, depending on the type of structure considered, linked to farmer's system conditions. In the modified conceptual model this thought is confirmed, but a key constraint is added.

The "new" idea assumes the fact that changes in irrigation structure are subject to the structure intrinsic capacity built by the farmer investments accumulated step by step. In particular, when farmers' physical capital reaches a certain ratio level compared to the level of farm-income owned by the same, so farmers could change their irrigation structure. Until this ratio not achieve the fixed level, farmers haven't the capability to

change their structure.

This constraint could be seen as the augment of the efficiency of physical capital owned by farmers, represented by the irrigation structure first, and secondly, according to Hasselmann's view, by technological and human capacity, growing when constant efforts in terms of investment are made. This investments could be seen as technological improvements or as a sort of learning by doing effect that augments human capacity.

Also this case, like the insurance one, if efficiently implemented could represent a possible way to face climatic risk; in fact a more efficient management of the infrastructure system could protect farmers from climatic risk, through an efficiently water use deriving from improved irrigation structure. This could represent an other possible way to adapt to climate change, by influencing production indirectly from investment in production factors.

#### *5.2.4 Climate Services Potentials*

The role of climate services in the described analysis is those to support farmers in their decision-making by providing climate information in a correct and usable way.

In our implementation of the model the role of climate information is not modified compared to the logic of VLW.

The crucial importance of climate information in the model concerns the fact that they assume the role of key constraint for farmers' decisions, in terms of crop selection and water use as well as for economic decisions.

In fact, from an economic perspective climate data, being particularly related to the compute of actual yield, determines indirectly the amount of profits that farmers' could destine to their investment options. In that way, affecting production and in that manner farm income in the medium/long term, also the future decisions about investments will depend from climate forecasts.

It is evident the fact that, in this model as for others in existing literature, climate services play a key role in determining some system dynamics that, in particular in our case, are at the bases of the overall behaviour.

To improve climate predictions and their provision by climate services is desirable in such a way to project more reliable decision-making. In the involved model, this could be positive in a way to decide to focus efforts in a specific direction, concerning actions as well as resources. In specific farmers, providing real information about future climate conditions, could plan in a more efficient way production and investments decisions.

For example, a growing reliability concerning climate services could lead farmers to undertake product-intensive strategies, focusing on production and investment in infrastructure in a way to augment production performances.

Instead more uncertain climate information could lead farmers behaviour into more conservative strategies that, in our model, result in a propensity for insurance practices, that could limit the made efforts in production activity, channelling on the other hand major funds to limit climate risk deriving from less reliable climate information.

#### *5.2.5 Future Developments for VLW Model*

The next step in consolidating this analysis consists in building an operational model for VLW case study. This effort aims to augment the consistency of our analysis, providing valid results about our reasoning.

The previous paragraphs presented the conceptual model for the Venice Lagoon Watershed case study.

Now, following the proposed “personal” UML logic, using the Simile Software<sup>52</sup> we provide an Agent-Based Model structure that would represents the described system.

Simile is a simulation software that represents interactions in two ways, by

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<sup>52</sup> Simile software: <http://www.simulistics.com/>.

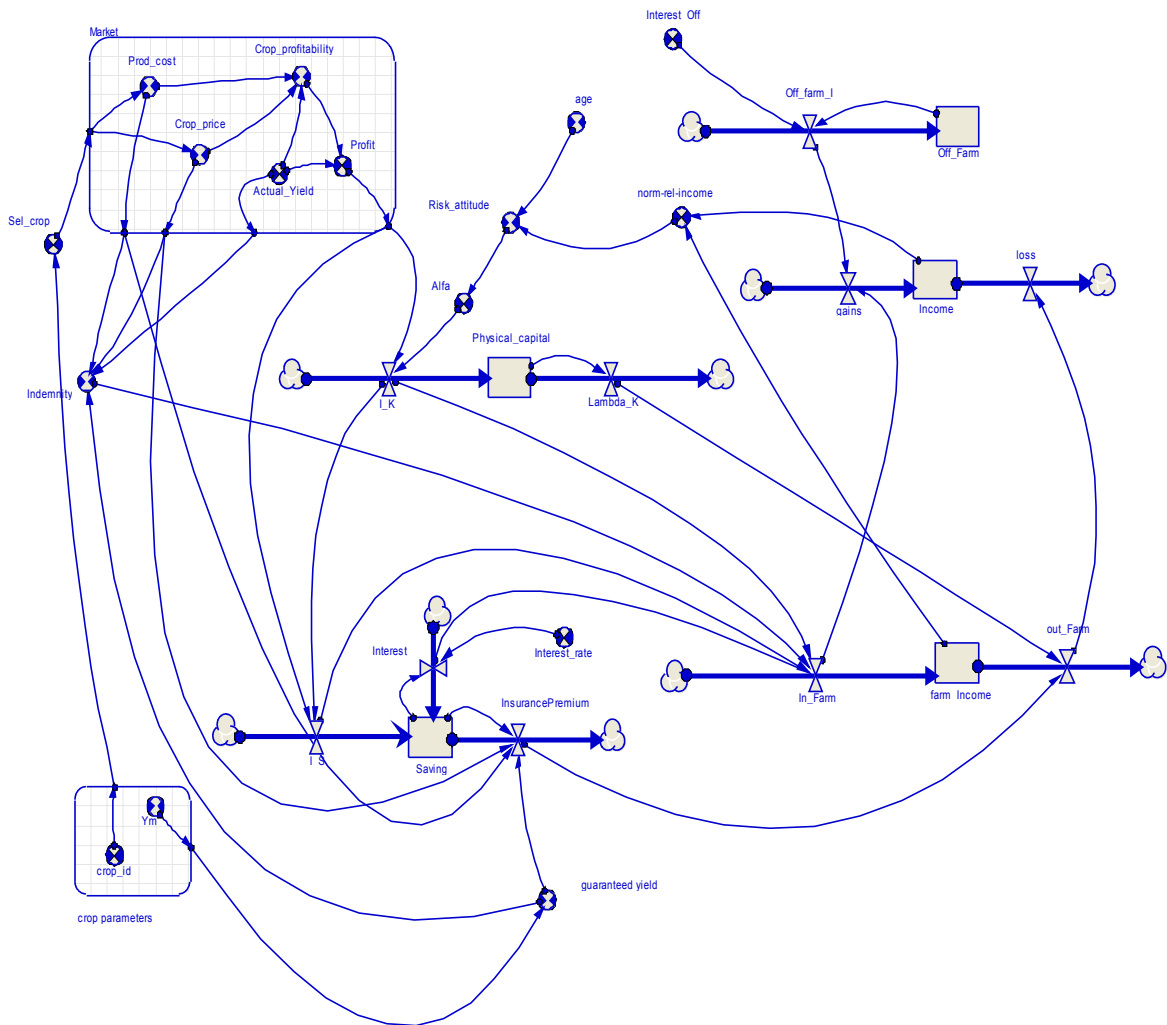
diagrammatically method, representing actors' relationships and by a declarative procedure that allow to describe procedures in a consolidate language.

By Simile we aim to create a dynamic sub-model for farmer agents based on UML conceptual model. We would represent the mentioned farmers' decisions about profits' allocation and the relative connections with income entity.

Using this method we would provide a complete compartment of the variables taken into account, showing the interactions occurring within these. These linkages, once have been setted through appropriate functions allow the system to be ready for several simulations, therefore giving some tangible outputs to be evaluated.

The presented one is only a sub-model, that have to be inserted into the complete Simile VLW Model that would simulate the functioning about the entire system.

The figure in the following page provides the first representation for the farmer decision-making, following the logic described in the UML “modified” model.

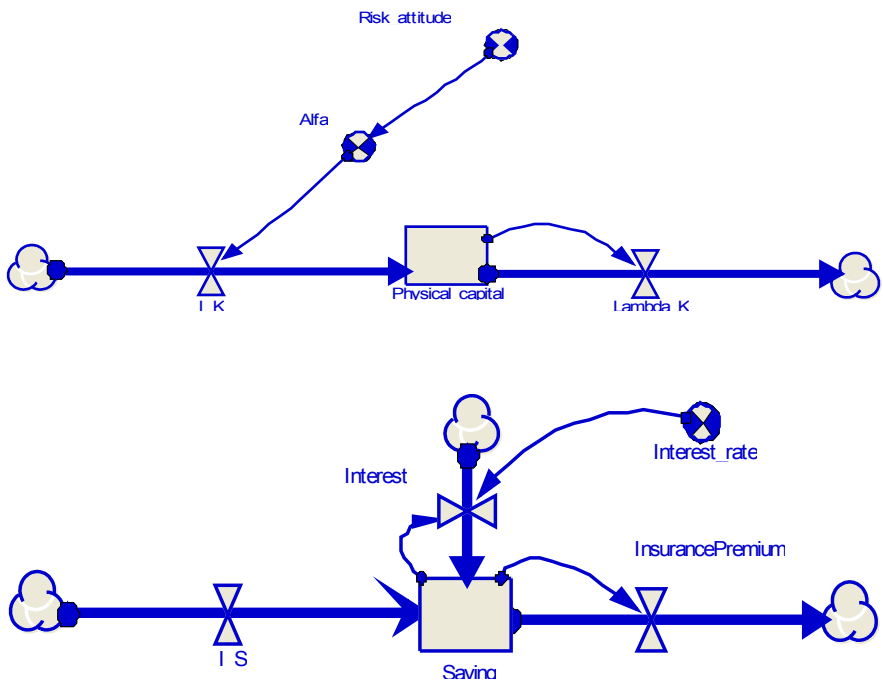


**Figure 22** represents the first snapshot given by Simile software about the structure of the system proposed in UML model.

In the showed Simile version the key entities described in UML specification are presented as variables, stocks or flows, depending on the role they play in the modelled system.

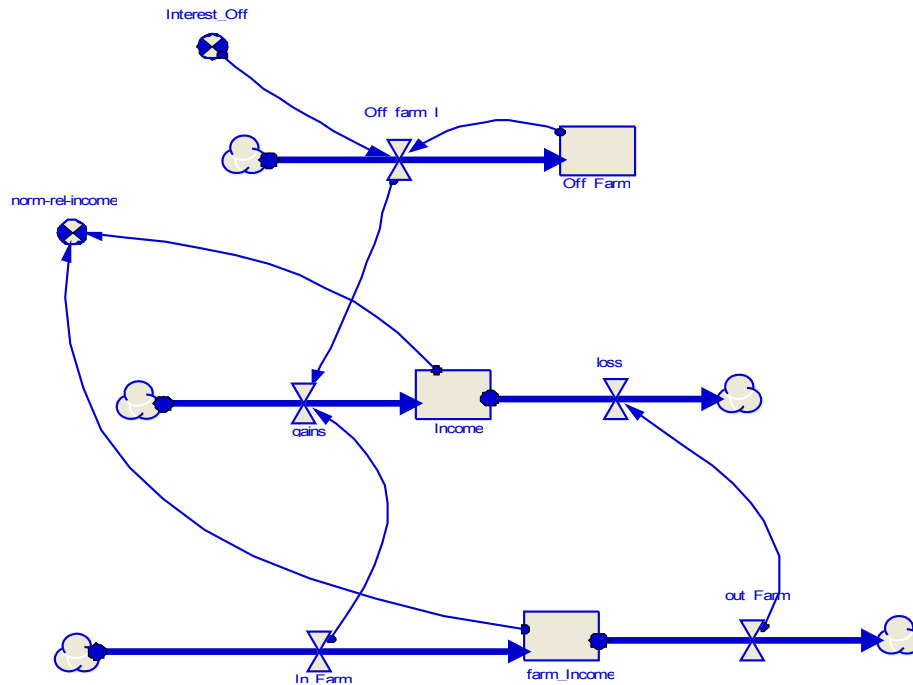
In our case *physical capital* is represented by a monetary stock, as *savings*, while *indemnity* is a variable that influence system behaviours subject to particular conditions, already describe in UML.

The patterns relative to the two cited stocks depending from an inflow and an outflow. In the case of physical capital the inflow is represented by the discussed investments derived from profits, while the outflow is represented by the physical capital depreciation. For savings, the inflow is given from the profits' allocation to savings and the matured interests deriving from this investment, while the outflow is constituted by the insurance premium paid by the farmer. The next two diagrams show these “stock and flow” logic.



**Figure 23 and 24** represent the stock and flow diagrams respectively for physical capital and savings.

About the entity constituting *income*, in the Simile version of the model we represent total income and its two components, farm and off-farm, in stock entities too. The diagrams below show this representations in details.



**Figure 25** provides the representation, using Simile Software, for incomes entities and describes their composition as “stock and flow” proceedings.

The inflow for *farm income* is constituted, as described in the UML model, by the positive variations of *physical capital*, *savings* and *indemnity* step by step, while the outflow is given by negative variations. The stock *off-farm* instead is not dynamic as the farm one. As said we only assume that this entity grows at constant rate of interest. The combination of farm and off-farm incomes determines the stock of the total income; all the three entities evolve together each time step.

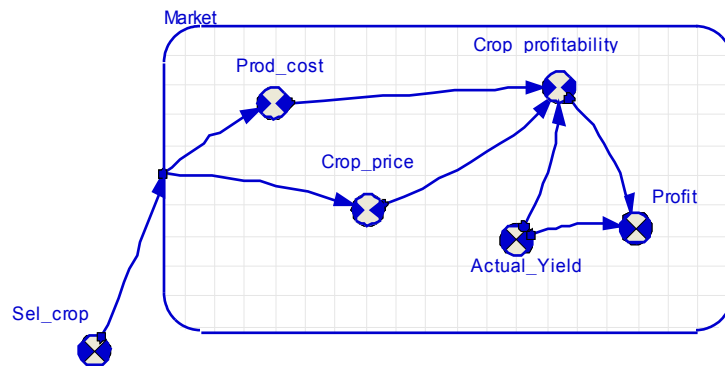
Income stocks too have to be considered in a monetary way. In this manner the entire system described, that make all the stock and flow systems interacting, represents in few words the monetary system for the VLW model.

This subsystem is governed by an investment strategy undertaken by farmers' decision-making. As said the resources to allocate between physical capital and savings are



provided by market system, through the determination of farming profits, deriving from crop production.

The market representation into the Simile model is given by the following diagram, showing how market signals influence the determination of profits.



**Figure 26** constitutes the subsystem market, represented by Simile software.

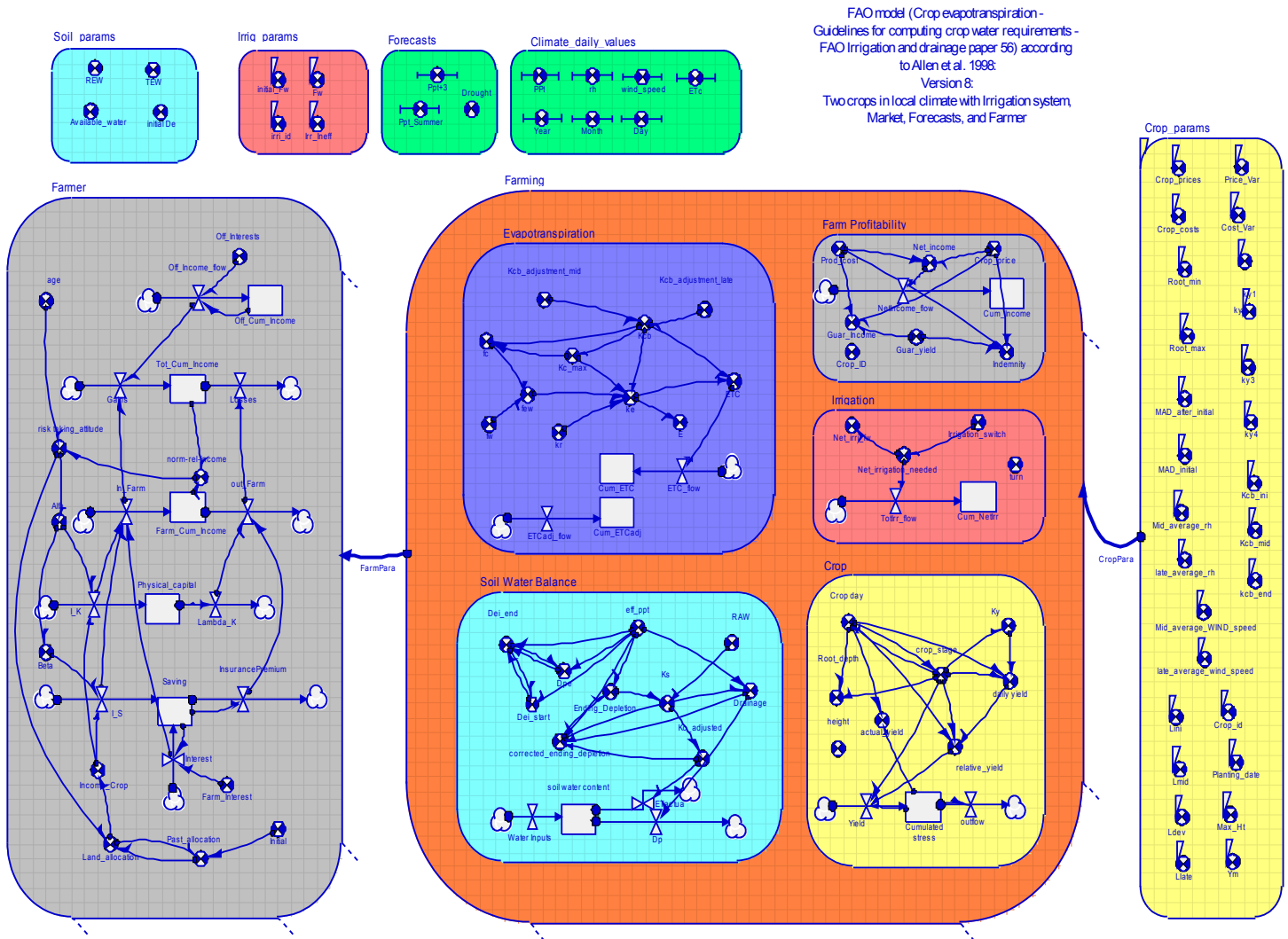
The definition of this sub-model is crucial, providing the amount of resources to allocate by decision-makers.

An other important condition has to to be highlighted. As specified in the UML construction, the variables of the model evolve step by step, but strategic decisions take place only at the beginning of each year. So it is important to define a condition into the model specification that could identify the day in which strategic actions are undertaken.

This sub-model is not defined at all. Some functions are well defined while others are developing, in a way to be inserted into the entire Simile model.

The final goal is those to integrate this subsystem into the more complex model representing the entire VLW case study. Following this perspective signify that the provided sub-model is continuously developing and have to be inserted and modified step

by step in the complete version of VLW. This procedure are developing following the structure provided below.



**Figure 27** provides the representation in Simile about the integration between FAO concepts and the economical perspective introduced in UML model.

The presented Simile diagram is the developing complete model, integrating the FAO logic with given parameters, climate information and forecasts, market and farmers' decision-making.

For instance this version provides only the behaviour of a single farmer. For future developments an integrated version involving  $n$  farmers is provided.

In a way to finally consolidate our analysis, the farmer logic presented in this chapter, that integrate the considerations given by Balbi et al. (2012) for the existing VLW model, has to be merged in the complete system represented above. The resulting system gives a farmers' sub-model changed compared to those represented in Figure 22, because of the integration required in merging different systems.

This process is developing, so it's not complete at all. Relationships' specification has to be validate in future analysis.

For example this version of the model involves only one farmer and try to explore the associated behaviour. Next step in enlarging the analysis could involve several farmers with heterogeneous characters, as the original VLW model aim to.

Now, by the use of Simile software various simulations could be done in a way to explore reactions subject to determined conditions or parameters.

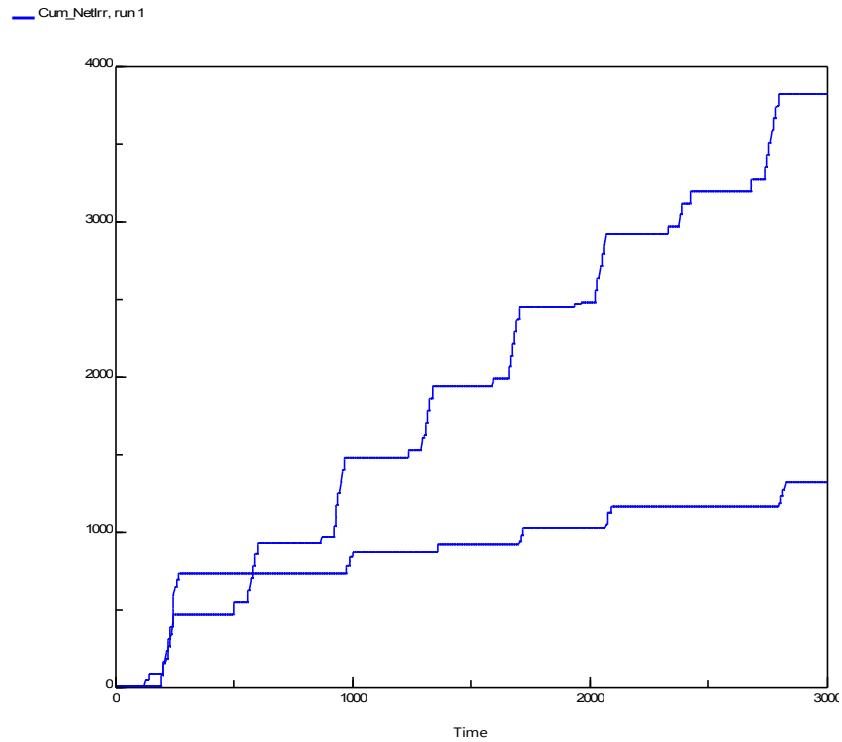
This could lead decision-makers to better understand system behave and to better project actions to undertake for the future.

To do this, it is important to well consolidate the existing structure of the model, presented in Simile by Figure 27 and in that manner, starting from a valid basis, enlarge the analysis to the heterogeneity of the entire system.

Following, we only show an example of resultant from Simile simulation.

The proposed graph represents the simulation regarding the cumulation of irrigated water. In particular we can observe two patterns, corresponding to the different needs deriving from the two different crops involved in our system.

We can see that, in the case of maize, the irrigated water grows continuously, while for winter weat the used water is less, according to the less quantitative needed by this crop compared to the other one.



**Figure 28** represents the pattern involving the cumulated stock of water irrigated for the two considered crops.

This is a case in which the model can represent quite closely the reality.

The aim of the entire model is obviously to provide these types of results regarding all the existing variables and processes, replicating behaviours in a right way and so, finding correct and efficient solutions for the associated issues.

## **CONCLUSIONS**

The importance of adaptation to climate change is quite consolidated within climate change literature and among the involved decision-makers.

This practice could be not only useful to limit some bad impacts and to allow the system to survive through numerous existing perturbations but also becoming a valid option in differentiating the performances of some systems, turning in advantage the potential negative effects of climatic impacts.

To undertake these actions in an optimal way, climate services represent the way by which information are provided, diffused and used across multiple actors and functions. Therefore, the importance to integrate climate services in coordinated global networks able to provide the correct and necessary information for different decision-makers seems to be fundamental in approaching adaptation problems within different uses and sectors.

In this thesis, adaptation to climate risk refers in particular to the agricultural sector, in which these actions play an important role, protecting agents and activities from climate variability. In this particular field, the ability to vehicle information into the right way could bring the system into an efficient evolution path, for example managing efficiently crop selection and the respective yields, water needs or agricultural infrastructure systems.

As seen in the Venice Lagoon Watershed case study, one of the most suitable methods in approaching adaptation problems is represented by the use of Agent-Based Modelling. This methodology allows decision-makers to investigate complex systems, as socio-ecosystems are, analysing relationships and the deriving emergent properties among different actors and using different logics.

The flexibility of ABM instruments is probably the most important characteristic of these models, that allows decision-makers to make evaluations within multiple heterogeneous actors and functions, and to provide some evidences in contexts of high complexity that otherwise would remain unknown.

The presented version of the Venice Lagoon Watershed model is an ABMs based on UML method.

By establishing conceptual relationships among several entities constituting the system under analysis, the specific model aims to compute water needs associated to defined agricultural practices under the pressure of climate change. It was developed as a typical agricultural model for the Venice Lagoon territory, which take into account only marginally the farmers' economic behaviour.

This thesis aim to include some conceptual tools related to some socio- economic behaviour, in such a way to explore some potential adaptation options, respecting the logical background standing on the bases of the model, and to explore how climate services could interact with these “new” concepts.

By exploring the logic of this model we have found that some socio-economical issues, could represent interesting strategies to adapt in a context of changing climate.

According to the considerable importance that several research bodies give to investment in land and capital in contributing to economic growth, and to insurance practices in assess strategies against climate risk, we define two different adaptation options that farmers could undertake through a particular investment strategy that allows them to allocate profits in different ways.

These strategies correspond to invest in physical capital, farmers' owned irrigation structure, or alternately to allocate some share of profit in savings, in a way to accumulate resources to undertake insurance practices.

These alternative behaviours depend on farmers' risk attitude.

In the cases already existing or potentials for future analysis, climate services play a crucial role, being the units that allow farmers to plan action in advance and in an efficient way.

In this sense climate services improvement is a central driver; by augmenting their reliability and conversely reducing uncertainty, climate information could lead farmer into different behavioural patterns, as regards agricultural practices as well as economic

choices.

The model under analysis has to be considered context-specific as the generality of ABMs usually are. In that manner the obtained conclusions refer to the specific context under analysis, not being general findings.

The potentials resulting from our analysis have to be verified and tested for other specific contexts or by introducing different assumptions in a way to assess if a degree of generality exists. Several assumptions could be placed on top of our analysis, considering aspects that to date we have not taken into account.

These considerations, excluded from our actual analysis, could be involved in future implementations.

For example conjectures about the role played by off-farm income could bring some new implications in terms of farmers' strategies, including for example some activities that a farmer could develop parallel with agricultural one, contributing to total income as well as farm activity.

The VLW model is based on a logic that considers farm system as central for the analysis, and our implementation is relative to this specific micro-system.

Nowadays globalisation involves societies' systems and their activities. To enlarge the boundaries of the system under analysis could be useful in a way to explore some relationships from micro to macro scale, in a way to represent globalised society.

From the economic point of view for example, understanding how farmers interact each other in a more complex market system would be interesting and could allow decision-makers to analyse new important market issues, determining new strategies or better defining the proposed ones.

We mentioned investments in land and water management as one of the more interesting operations to carry out in agricultural field for economic development, and to strengthen the influence of these improvements at macro-level too. Regarding these investments, an important role could be played by public and private investments, by facilitating the

provision of necessary capitals.

According to this view, introducing a financial market sub-model to represent the access to credit for farmer agents, could be an other important amelioration of the existing conceptual model, further enlarging system boundaries including also financial aspects.

For climate services too, ABMs are charged to receive several inputs, in a way to test for example how different degrees of uncertainty associated to climate services and information could lead actors into different behavioural patterns.

To receive reliable information about climate change, especially for the future, it is an aimed goal for the entire society. Furthermore this aspect is relevant also for the model we treat in this thesis, because of the fundamental implications in terms of socio-economic behaviour arising from climate data and forecasts.

It is evident that, to include all these possible implications would make the degree of complexity of the system to grow exponentially.

So, it is important to proceed consolidating step by step the existing knowledges, in a way to include new considerations in next analysis.

Also for our case study, first of all it will be important to test the consistency of our considerations by their integration into a quantitative model.

About this, a quantification of the model is developing through the utilisation of Simile software, in a way to build a model in which all the cited relationships are involved.

The goal of the developing work is to provide concrete results, verifying the real weight for the given considerations. In this way the entire VLW model could be validated in all its assumptions and its highlighted potentials, proposed in the UML version, and so used as efficient instrument for decision-makers.



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