

A SET OF LOGICAL STEPS IN ORDER TO MAKE AN ASSESSMENT OF CLIMATE CHANGE IMPACTS ON AGRICULTURE

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INTRODUCTION

During many years quite a lot of participants in international training workshops about the subject of impact assessments of climate change approached this author, or wrote him by e-mail, asking for orientation about which steps they should follow in order to be able of making their own impact studies. This situation has persisted in spite of the availability of already classical books on this subject such as Benioff et al. (1996), Parry and Carter (1998), UNEP (1998) and my own Workbook (Rivero, 2008), that is available from the homepage of the INSAM website.

This persistence may be attributed to the fact that books such as mentioned have not been so widely distributed in developing countries as they should, but this author thinks that there could be other reasons. They might be related to the fact that the aforementioned literature is not really easily understandable for beginners, especially in developing countries, and many times do not address this question in a clear direct way. It could also be said that there has been a trend of depending and relying upon foreign institutions and research teams for making such kinds of assessments, instead of developing national capacities and scientific potential for this purpose.

These reasons induced this author to write the present document aiming to help clarifying this subject for beginners with a minimum training on the subject. This paper should never be taken as the general consensus of the climate change impact community about how impact assessments should be done, because the author does not consider himself as a recognized leader of that community. This paper is only a personal opinion and an example of the way in which this specialist has worked in climate change impact assessment on agriculture during fifteen years. In some way, it could be considered an appendix of the aforementioned workbook.

This paper was only written in order to clarify what someone should do when his higher authorities have assigned him/her the task of making an assessment about the expected impacts of climate change on agriculture or certain part of it (e.g. specific crops or types of management, livestock production, and specific production areas). That is, before asking for help.

Even if it could be considered as somewhat awkward in scientific literature, this author has chosen to write this paper by adopting the position of an impact team leader who has been requested to conduct a climate change impact assessment on agriculture. Even if this is not the usual academic style of writing, doing it in this way will put the reader in the same

position as the author and it is much easier to write because of the emotional involvement required to feel really immersed in a climate change impact assessment. Sometimes, belonging to the impact team will be expressed by the personal pronoun “we”. This can be considered a common way in which we Cubans convey the feeling of belonging to a larger community, striving to achieve a higher common goal.

I really hope that this modest effort can be of some help for those people planning to do something with these climate change issues.

FIRST STEP: Definition of the problem

The assessment at hand should be first extensively appraised in an open exchange between the specialists that are going to do the assessment and the authorities who asked for it. Only through this exchange it will be possible to estimate the extent and depth of the assessment, including even the feasibility of it, according to the available data and tools necessary to do so. One possible conclusion could be that the assessment is not possible as it has been initially expressed and only some variant of it is really achievable.

In going through this stage, the impact team should have to keep in mind many factors that will be more specifically addressed in other steps of this process.

EXAMPLE 1.1: Our higher authorities asked from us to make a climate change impact assessment on all sectors, including agriculture, for the Second National Communication to UNFCCC. They were initially speaking of three different regions of our country and provided us with a listing of most important crops and agricultural activities from the point of view of the Ministry of Agriculture.

We declined to do the third region, because there were very few agricultural activities there meriting assessment. We also declined to do the second region, because it was too large and topographically complex, which would require assessments in different parts of a river basin and the use of a Geographical Information System in order to integrate results. We accepted the first region which was an extensive plain, with a very important dominant soil type, in which a lot of important agricultural activities have been taking place since the end of the nineteenth century. We chose to study two quite relevant crops, because we knew that we had at hand 3-4 biophysical models able to simulate these crops and that they were mostly cultivated with high level technologies in irrigated conditions. These facts allowed us to use the concept of potential yields, in order to assess climate change impacts on these crops – if we chose a crop like sugarcane then we would have to calculate rainfed yields, which were much more complicated to estimate. Having chosen those irrigated crops, we claimed – and received – the right of making our own assessment of the water resources sector. In doing all these analyses, we already knew that we had enough historical climate data for the region at hand. You can’t do any assessment at all without having a minimal amount of climate data available.

Then they asked from us to study an additional specific crop because of its importance in the national food balance. After some very detailed discussions, we accepted this reluctantly, because we knew that we had at least one impact model able to simulate (with some limitations) the development and growth of this crop. The problem here was that we had no real experience simulating this crop and we were insecure about being able to do a satisfactory analysis of the expected impacts of climate change. In making such assessments, a lot of ethical considerations are involved, and by no way at all are we going to adopt a position that will jeopardize our credibility and mislead our higher authorities.

As to animal production, we then chose swine production instead of cattle, because we had recently finished an assessment on cattle production in our area and because we just had acquired a usable model for swine production that we wanted to apply for the first time in our country.

In this form, our first step was fulfilled. Here we described it easily, but it took a sizable amount of national specialists, the realization of three workshops and a few months of work to arrive to a generally acceptable consensus.

SECOND STEP: Creating a reference climate dataset.

A reference climate dataset is necessary in order to do a climate change impact assessment. Because an impact assessment must be done – because we can't admit that our decision makers have to work in the dark – some way of creating a reference climate dataset must always be found. For strict scientific studies, you would require a comprehensive data set built with 30 years of daily values for each relevant climate variable such as maximum and minimum temperature, precipitation, water vapor pressure, global solar radiation and wind speed. It's almost impossible to build such a dataset in developing countries. That's why for practical purposes, many times you will have to deal with less complete climate datasets, comprising a lesser number of years (10, 15, 20...). We also must often forget about daily values and work with mean monthly values instead. A lot of solutions are possible and Chapters 1 and 3 of the Workbook deal with them (Rivero, 2008).

EXAMPLE 1.2: For the chosen region we knew that we could count on three different meteorological stations. We found that we could make a reference climate dataset representative – but incomplete – for the 1961 – 90 period, consisting of monthly means for all climate variables needed except for global solar radiation. We also realized that we additionally could build a complete daily dataset for the period 1994 – 2009. Global solar radiation – never measured in these stations – was estimated by using an empirical approach based on maximum and minimum temperatures. So we built two different completely independent reference climate datasets.

The monthly means dataset and the daily values dataset were used in subsequent steps with different impact models, because there are models able to work with monthly values as input

data and other models where this is not possible at all. You may see Chapter 3 of the Workbook on it.

Finally we built a third reference climate dataset, comprising only annual mean values for temperature and precipitation. This reference climate was used because one of our impact models – the Budyko physico-climatological approach – needed only annual values for assessing climate change impacts on annual water balance terms required in water resources assessments. Approaches based on such kind of climate indexes can be found in Chapters 2, 6 and 8 of the Workbook.

THIRD STEP: Choosing adequate impact models.

In every assessment you will have to use one or more impact models. An impact model of change may be defined as a model whose outputs vary when you specify different climate conditions as inputs. Generally, impact models used in agricultural assessments give different outputs even for the same climate data as input if you specify different crops, varieties, soils and management conditions. An impact model may have many different forms, depending on the assessment it is intended to do. But in our case, its outcome necessarily should depend explicitly on one or various climatic parameters. As impact models in the agricultural and water resources sectors, our team strongly recommends the use of crop models based on plant physiology, animal behavior or response to climate conditions based on animal physiological knowledge, and the use of climate indexes and laws of physical climatology. Different impact models are discussed in Chapters 2, 3, 5, 6, 7, 8 and 9 of the Workbook.

But you have to realize that there are crops or aspects of food production for which there are no models available at all. In such cases you will have to use “ad hoc” procedures, even if that implies changing usually relevant parameters. As an example, we were able to prevent planting a given crop in some parts of our country because FAO said that satisfactory economical results for this crop were only attained in climates where monthly precipitation exceeded reference potential evapotranspiration during seven months of the year. Our calculations for this parameter told us that this condition was attained only during five months of the year in the region where they were going to plant it. When we told them that they would have to put kilometers of pipes and allocate a water source in order to irrigate the crop during most of the year, they decided not to plant. Criteria as this one could be used also in forecasted situations for future climates, because this requirement – not fulfilled today in actual climate conditions – could become true in a future climate, making the cultivation of that crop possible where it wasn’t before. It is obvious that such rules of thumb could also work in an opposite direction, making impossible tomorrow what is possible today.

EXAMPLE 1.3: As we had no previous experience with the third chosen crop, we decided to use our most simple and intuitive model in order to study it, that is WOFOST 4.1 (Diepen et al., 1988). This model can only work with monthly climate data as input, so it was in agreement with one of our reference climate datasets. See Chapters 3 and 9 of the Workbook.

As to the other two crops, we had three well-known models able to deal with those crops so we used them all. One of them is WOFOST 7.1.2, a model that can deal with monthly or daily climate data as input. The others were two of the models embedded in the DSSAT series system. These last models can only work with daily climate data as input, as you can read in Chapter 3 of the Workbook.

Animal production can't have a crop model of course, so we centered our hopes on estimating values of the Temperature – Humidity Index (THI) and relating it to different parameters of the chosen animal behavior and production. Additionally, we used a specific swine model available on the Internet. You may see Chapter 8 of the Workbook about animal production.

Water resources cannot be completely assessed with these tools, so we decided to model the different parameters of the equations for annual radiation, water and energy balance using Budyko's approach. See Chapter 2 and 6 of the Workbook.

FOURTH STEP: Applying impact models and tools to reference climate datasets.

First, you must calibrate – comparing with real data and farmers' appreciation - your impact models and tools in order to understand their capabilities and limitations. Strictly speaking you should even validate those models with real experimental data, something that many times is not possible in the underdeveloped world.

Once your impact models have been calibrated, you must then apply all your selected impact models and tools to the reference climate dataset. This must always be done in order to obtain a complete set of simulated responses of crops, animals and water resources to actual (reference) climate conditions. Because you will need a simulated set of actual climate responses in order to study later how these responses will change in different foreseen future climates (climate change scenarios) during the 21st century. First of all, you may discover with these sophisticated tools many traits of behavior of crops, animals and water resources of which you were unaware before running the models. You must do all the necessary efforts consulting agricultural specialists, farmers and traditional experience in order to confirm that those traits are really observed in agricultural practices.

It happens that something as your simulated potential yields being higher than real ones will occur very frequently, because potential yields are actually attained only in very favorable conditions in a high input agricultural system. But the model could be simulating correctly the actual seasonal pattern of yields obtained with an optimal irrigation system.

A result indicating that most C3 short-cycle crops have their highest potential yields during the cool season of the year, will be hard to understand by farmers under a rainfed management condition. Because they have never planted those crops in winter, and winter is usually totally included into the dry season in many tropical climates. Rainfed agriculture during the dry season is generally avoided. This means that you should then run a large set of

simulation experiments in order to study rainfed yields. Then they will recognize easily the actual seasonal behavior of their real yields.

Three months ago I gave a three hours lecture to PhD. students in the Superior Pedagogical Institute "José Martí" in Camagüey. Rather uneasily I threw at them our still not peer-reviewed results about swine production. But it happened that there were in the audience two specialists in this field. It was a real experience to hear those two experts enthusiastically confirm every modeled conclusion related to the influence of climate conditions on pig's behavior and production. That was one of the happiest days of my life.

This step is generally very complex and requires a lot of thinking and hard work. Even if you stop here and never continue to estimate climate change impacts, the results of all the previous discussed steps constitute already a scientific study that you may apply in many different agrometeorological services.”

This fourth step is generally complex and requires a lot of thinking and hard work. Even if you stop here and never continue to estimate climate change impacts, the results of all these four discussed steps constitute already a scientific study that you may apply in many different agrometeorological services.

EXAMPLE 1.4:

Using mean monthly values from one of our climate datasets, representing 1961 -90 reference climate for the study region, we then chose 12 or 24 different planting dates through the year and simulated duration of the two main phenological stages (the vegetative and the generative one) and crop's potential yields. Then the daily data series for 1994 – 2009 was transformed into a monthly data series, only that in this case this dataset now was a time series containing information from January 1994 to December 2009 (month by month, so there are 16 values for January in the series and so on).

Running models of the WOFOST series with these different data sets allowed us to estimate not only mean values of relevant parameters but also its standard deviation associated to natural climate variability for every representative planting date. Only generic crops were studied in this case (Heemst, 1988).

Results showed convincingly that crop responses in each one of the three locations previously chosen, and in both climate datasets, were very similar in respect to simulations of potential yields and duration of phenological stages. This was taken as a confirmation that all those localities have very similar climates and that climate had not changed substantially from one period to the other. You could reach this conclusion by examining climate data in a direct way, only that concluding this from crop simulation experiments is much more interesting and original. Results could have been very different if we had studied rainfed crops, due to the fact that the space – time variability of precipitation is very much higher than the usual variability of temperature and global solar radiation.

Following this study now we did a set of simulation experiments using the complete daily climate dataset using models available in the DSSAT series. By restricting ourselves to use

only the most significant planting dates we could then simulate not only generic crops but a certain set of different varieties ranging from 3 to 52.

Results obtained with these different crop models were consistent among them. But now we could conclude that different varieties are differently adapted to our climate conditions – that's what varieties are for. In fact, creating and introducing new crop varieties more resistant to the expected warmer climate conditions is a promising and strong adaptation option to climate change.

In relation to swine production we used largely a set of empirical statistical relationships between a concrete monthly Temperature – Humidity Index (THI) and a large set of different parameters characterizing swine production that go from voluntary food intake to pregnancy and mortality rates. Results obtained were dramatically consistent with actual farmers and industrial experience.

Results obtained studying water balance terms using a water balance approach and climatic indexes for the whole country have been already presented in international congresses. Many of those results could be validated by comparing them with previous national maps that have been done in our country by national and foreign scientists since the first quarter of the twentieth century. As we will explain later, this was the second time that this assessment has been done in order to study how those maps will look at different future dates during the 21st century. But in this case new climate change scenarios and more powerful climate indexes were used in the next steps of the assessment (Rivero et al., 2009).

When we finished this step we had already one third of our assessment ready to be made public. Results are being peer reviewed by national institutions and authorities and will be released to a wider audience in 2012. But it is common practice that this characterization of simulated responses of the objects studied in reference climate conditions is never done as an independent study, remaining then only a part of the whole assessment that now will include the introduction of climate change scenarios and similar simulation experiments in future climates. Only climate conditions will be different in the second part of the assessment because any other changes, let's say different management conditions in future climates, will be introduced in the third and last stage of the process.

FIFTH STEP: Creating future climate change scenarios

You can't do an assessment of climate change impact on anything without first building a set of climate change scenarios. That is a set of expected values for different climate variables during 2020 – 2050, 2050 – 2080 etc. etc. The dates may be chosen by the impact team or requested by higher authorities. Climate change scenarios may be built in many different ways but we prefer to use methods based on climate (physical and numerical) modeling. For preliminary appreciations we sometimes use synthetic (arbitrary incremental) scenarios. When available climate models don't provide us with all the necessary variables, then we use a kind of mixed approach that we use to call Bultot's scenarios. Climate change scenarios can

also be borrowed from foreign sources, as there are a lot of such kinds of scenarios available from different sources (there are some Web sites where you can download climate change scenarios for many countries). But we don't advocate the use of this approach because generally they don't have all the necessary climate variables. They also let you no freedom of choice among different Global Climate Models and Greenhouse Gasses Emission Scenarios. See Chapter 1 of the Workbook.

In this step you will find one of the hardest parts of building climate change scenarios: the problem of downscaling.

Global Climate Models (GCMs) and Regional Climate Models (RCMs) usually provide as results mean cell values. In the first case cell size may be 2.5 by 2.5 degrees while in the second case they may be 50 by 50 or 25 by 25 kilometers in size. It happens that a whole country such as the Dominican Republic or Puerto Rico could fit nicely in only one cell of a GCM, while one very small country such as Niue could fit in only one cell of a RCM. In order to get some detailed view of climate inside one grid cell, you must downscale results from a climate model to a different scale representing different climate regimes within your country, and you must be able to differentiate plains from mountainous land or coastal areas from inland locations. Downscaling is a very complex process and very much addressed in climate literature. It can be done by one standard approach such as the one described in Benioff et al. (1996), or by using statistical or dynamical methods not described here. Regretfully, this rather complex process is barely sketched in the Workbook, in part because the scenarios building processes are normally very specific, coming from meteorological institutions and climate research centers. Generally, climate change scenarios are built by a separate research team not belonging to the impact assessment ones. The partial overlapping of these two different teams in our country could be considered a particular feature and not a general rule.

The subject of downscaling is rather tough, so we recommend that in the initial stage of climate change studies, people should use only the standard (simplest) downscaling approach. In this approach, changes in climate variables predicted by a GCM or RCM for a given grid cell are applied to actual reference climate observed variables. This is done in order to obtain expected future climate variables for different locations (meteorological stations) inside that grid cell, that is a climate change scenario for the given grid cell. This approach is a valid downscaling method and it also solves the problem that at the end you will have the necessary point data that most impact models were designed for to use as input. Most crop models were created in order to use point climate data and not area means.

EXAMPLE 1.5: Since the very beginning of all these studies, it had been decided to use high resolution 50 by 50 kilometer climate data from running the Regional Climate Model PRECIS embedded in Global Climate Models HadCM3 and ECHAM4 using SRES A2 and SRES B2 greenhouse gasses emissions scenarios (GGES). This is equivalent to use of four different climate change scenarios coded as ECHAM4 A2, ECHAM4 B2, HadCM3 A2 and HadCM3 B2.

Changes in values of climate variables for different future dates derived from PRECIS runs were then downscaled using reference climate datasets obtained from three different meteorological stations located inside the chosen study region. The process of building climate change scenarios for the study region, in order to apply crop models and animal production impact models in future climate conditions, was concluded here. In doing this we created some rather new and original methodologies that are not published yet and won't be described here.

Then we realized that the former procedure could not be reliably applied to the water resources problem. We then created additional climate change scenarios with the same GCMs and GGES but using the MAGICC/SCENGEN 4.1 system for the whole country (Wigley, 2003), station by station from the western to the easternmost part of our country. Expected values of temperature and precipitation were then used in the following step.

SIXTH STEP: Estimating climate change impacts in future climates

In order to estimate impacts you must now run all your impact models, changing only input climate variables, for all future climates that you created in the previous step. In this step you cannot change simultaneously climate input data and any other initial condition such as soils and crop management. Because results of your impact models will be dependent not only on climate change but also on others causes such as going from irrigated to rainfed conditions.

Once you have all the simulated outputs for future climate, then you will be comparing future values for relevant parameters with those obtained previously in the reference climate. This process will lead to the determination of climate change impacts on the relevant parameters that you chose at the beginning of the process. Relevant parameters are specified by the working team or requested by your higher authorities. Practically every parameter simulated in this process can be chosen for one or the other purpose, depending on the nature of the research, because what is important for someone could be irrelevant for somebody else. The process itself will help you in this problem, because you can select as relevant any parameter that reflects a significant variation with climate change, without even knowing whether this parameter will be important for one or other user of the assessment.

In the case of crops, most common relevant parameters are duration of phenological stages, final yields and water needs of crops. For animal production they may consist of milk, meat or egg production, thermal stress of livestock and related parameters. In the case of water resources, such relevant parameters could be chosen as duration and magnitude of recharge periods, total annual runoff and climatic indexes, from which aridity and desertification processes can be inferred. Total area food production and per capita food production could also be very relevant parameters. But their assessments would imply some kind of aggregation of results obtained in different localities, or one cross-sectorally integrated model such as MIIA 2.0, that contains technological and population increase scenarios also. Please review Chapter 7 of the Workbook.

Strictly speaking the assessment process ends here, even if your higher authorities usually request you to additionally propose a set of adaptation options.

EXAMPLE 1.6: What we described previously was exhaustively done for the chosen region for all previously selected issues. Results reflected important negative impacts in all the four climate change scenarios. They will be available next year. Similarities in expected impacts using different impact models were remarkable, so we may be quite sure of the general nature of those expected impacts.

In the case of the water resources sector, radiation, water and energy balance equations for every meteorological station in our country (standard approach for downscaling) were then solved using Budyko's approach. Subsequently climate change scenarios were created with the MAGICC/SCENGEN 4.1 system. This allowed us to obtain the expected future developments of aridity and water availability for the whole country, using different climate indexes. In parallel we also obtained the expected future developments of potential biomass density and net primary productivity. Results were already presented and published this year in an international climate change congress, regrettably in Spanish (Rivero and Rivero, 2011a; 2011b). You may see some of these approaches in Chapters 6 and 8 of the Workbook.

SEVENTH STEP: Designing adaptation options and strategies.

Designing adaptation options is a very challenging task – especially if you realize that, in principle, adaptation options able to counteract all negative impacts of climate change may not necessarily exist or be feasible in a given socioeconomic and cultural context or at the current level of available technologies. An adaptation option could be as simple as changing the actual pattern of agricultural activities by changing actual planting dates in rainfed agriculture. It could be as complex as changing agricultural management by going from rainfed to irrigated agriculture. It is advisable not to reject initially any – apparently science fictional - idea never heard of before, without going through the next step devised to assess the feasibility of that option and to determine its possible benefits or drawbacks by any conceivable means. Adaptation options could come from sectors apparently unrelated to actual agricultural practices, including some very desperate ones as abandoning agriculture at all and dedicating local or regional efforts to the development of other production sectors such as tourism. At this stage of our work, the realization of activities such as brainstorming could come up with quite some very innovative options in a context very much wider than the agricultural sector alone.

The very existence of adequate adaptation options may be questioned from the very beginning of this process. This is one more very important reason for keeping us working very hard on the subject of global mitigation activities in order to put a very well defined limit to the magnitude of climate change. This very menacing issue shouldn't reach a magnitude large enough as to disrupt completely our civilization as we know it.

Since the very beginning it must be understood that any conceivable adaptation options will convey their own additional and many times unforeseen impacts on a broader context than agriculture itself. Changes in agricultural management such as those related to irrigation, fertilizers, genetic engineering, pests, diseases and weed control, will be often associated with environmental, economic and cultural issues. A large part of these associated impacts can't be assessed by impact teams in which only agricultural and climatological experts are adequately represented.

A preliminary and elementary list of simpler adaptations options could involve:

- Changing planting dates and cropping calendars.
- Changing crop and animal production management related to irrigation procedures, application of fertilizers, integrated plant protection strategies, development and introduction of new crops or crop varieties, management of thermal stress in livestock production, water conservation procedures and many others.
- Changing the spatial pattern of agricultural activities (crop regionalization) by displacing actual areas for specific crops to new more adequate areas elsewhere in the country (such as planting potatoes at higher altitudes, from low lying valleys to higher level plateaus or high terrain, in order to avoid the negative impacts of increasing temperatures).
- Applying intercropping to reduce chances of total crop failure in monocropping (e.g. Stigter, 2010).
- Using agroforestry options for coping with meteorological and climatological risks (Stigter, 2010; Stigter, 2011) as well as creating suitable microclimates in intercropping with (farm) trees (Stigter, 2010; Stigter et al., 2011).

But you can never be so optimistic as to think that simple solutions will be always available for such complex problems as a sizable change in climate behavior. It is very easy to write papers on adaptation options such as “to develop and introduce in the field new crop varieties more tolerant to heat and water stress”. The problem is that the available genetic material for any crop may not contain the necessary potential as to be capable to produce a new variety able to withstand new foreseen temperatures and soil water availabilities due to climate change. A good example of this is paddy rice under increasing (especially night minimum) temperatures and diminishing water resources (e.g. Winarto and Stigter, 2011). Then you could hope to be able to obtain such varieties by genetic engineering, let's say combining C3 crops genetic characteristics present in rice and potatoes with those of C4 crops such as maize and tropical grasses. However, experience tells us that introducing genetic engineering as an adaptation option in food production is like opening Pandora's box – in order to be able to suggest such an adaptation option, we'll be facing quite a lot of scientific, technological and ethical issues.

EXAMPLE 1.7: Recognizing that profound adaptation strategies in our case study will require a set of deeper multidisciplinary and integrated impact assessments, actual adaptation options discussed were mostly of the simple type and a general nature, such as:

- Changing actual practices of agricultural development without taking possible future climate circumstances and climate change into consideration, by introducing what has come to be known as operational agrometeorology and response farming (e.g. Stigter, 2010).
- Developing and introducing new crop varieties with lesser water needs and more adapted and tolerant to high temperatures.
- Technological changes designed to reduce thermal stress in animals.
- Introducing new irrigation technologies and practices leading to a more efficient use of available water for agricultural purposes.

EIGHTH STEP: Assessing adaptation options

The impact team must devise some ways by which the expected results of proposed adaptation options can be quantitatively estimated before they are actually applied in the fields on a large scale. Adaptations are always a risky and costly process in which we can't afford to invest too much money, resources and efforts without having a considerable amount of certainty about benefits that will be derived from applying them. In principle, the expected impact of adaptation options should be addressed by small scale field pilot projects (e.g. Stigter, 2010) and/or by implementing them in a simulated environment and observing what are the predictions of the same impact models used in the vulnerability assessments in those new – supposedly adapted – conditions (Benioff et al., 1996).

But it's rather obvious that running the impact models with adaptation options taken into account will not necessarily allow us to estimate second order impacts of adaptations in aspects outside the range that can be trustable simulated by the given models. The latter aspects could be colloquially called "collateral damage". Additionally, it can be seen that the range of hypothetically possible adaptation options will be much wider than the range of options that can be realistically tried out in pilot projects or simulated by the impact models previously used in the assessments. A different set of simulation models – containing the subset of impact models used in the assessment – would have to be introduced in order to solve this problem.

Expert judgment – in conjunction with a strong participation of stakeholders and decision makers - will always be a very important tool here. Even if we have described what could have been called a "top-down" approach in this document, the process of assessing adaptation options would be very much easier if results of an actual parallel "bottom-up" approach were available at this stage. In fact, a "bottom-up" approach could even be implemented at this

stage of the process under a “farmer first paradigm” (Winarto and Stigter, 2011). For obvious reasons, no useful example of this process will be discussed here.

NINTH STEP: Final Report.

The writing of a full Final Report, including all materials used and results obtained in an assessment as this one, is a really awesome task requiring authors, coauthors and editors plus a support team of collaborators. Such a report would easily accommodate hundreds of pages, many references and an equivalent amount of tables and figures.

Be aware that such a Report will be of great importance to the scientific community – even if it may indefinitely remain in the state of gray literature – but it will be of very little use for stakeholders and decision makers. A summary report of twenty pages could accommodate the essential ideas about purposes, methodologies, results and recommendations in a form much more amenable to people outside the range of specialists in climate change impact assessments. And an additional brief communication of a few pages, describing objectives, results and recommendations, should be easily understood by stakeholders and decision makers.

Stakeholders and decision makers will be most interested in what results were obtained and what your recommendations are, but not in the way those results were obtained.

Final Remarks

It must be stated here that what has been described can't be considered a complete assessment procedure of climate change impact on agriculture, but only a first order biophysical impacts study procedure. Climate change will affect the entire food production chain from the stage of land preparation until the stages of harvesting, stocking, transportation and distribution of agricultural products. Even labor conditions of agricultural workers in the field will have to be appraised, as heat stress will be much more intense with climate change. Many economic questions will have to be considered also. In order to make an appraisal of all these issues, an integrated assessment procedure should be followed, even if the current understanding of what an integrated assessment is does not address such things as stressing labor conditions in agricultural fields. It generally requires a first order biophysical impact study procedure.

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