GUIDANCE NOTE:
LOGICAL STEPS FOR ASSESSMENT
OF CLIMATE CHANGE IMPACTS ON AGRICULTURE

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INTRODUCTION

During many years, numerous participants in international training workshops on the subject of impact assessments of climate change have approached this author, or written him by e-mail, asking for guidance on which steps should they follow in order to undertake their own impact studies. This situation has persisted in spite of the availability of already classic books on this subject such as Benioff et al. (1996), Parry and Carter (1998), UNEP (1998) and my own Workbook (Rivero, 2008).

This circumstance could be due to the fact that books such as these have not been as widely distributed in developing countries as they should, but this author also thinks that there are other reasons – mainly that this literature is not easily understandable for beginners, especially in developing countries, and often does not present the topic in a clear and direct way. It could also be said that there is a tendency to depend and rely upon foreign institutions and research teams for undertaking such assessments, instead of developing national capacities and scientific potential for this purpose.

These reasons have led me to write the present document, to help clarify this subject for beginners with 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 doesn't consider himself as a recognized leader of that community – but only as a personal opinion, and as an example of how this specialist has worked on climate change impact assessment on agriculture during 15 years. It could be considered an appendix of the aforementioned workbook.

This paper has been written only to clarify what someone should do when higher authorities have assigned him/her the task of assessing the expected impacts of climate change on agriculture or a certain part of it (specific crops or type of management, livestock production, and specific production areas). That is, before seeking outside assistance.

The author has chosen to write this paper from the position of an impact team leader who has been requested to conduct a climate change impact assessment on agriculture. While not the usual academic style of writing, this approach places 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 is how we Cubans convey the feeling of belonging to a larger community striving to achieve a higher shared goal.

I truly hope that this modest effort can be of assistance for people like yourselves, committed to tackling climate change issues.

FIRST STEP: Definition of the problem

The assessment at hand should be first extensively considered in an open exchange between the specialists assigned to do the assessment and the authorities who have requested it. Only through this exchange it will be possible to estimate the extent and depth of the assessment, and even its feasibility, based on the available data and tools. One possible conclusion could be that the assessment in not possible as initially envisioned, and only some variant of it is really achievable.

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

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

We decline to assess the third region, because there are very few agricultural activities there meriting assessment. We also decline to assess the second region, because it is too large and topographically complex, which would require assessment in different parts of a river basin and the use of a Geographical Information System in order to integrate results. We accept the first region which is an extensive plain, with a very important dominant soil type, in which many significant agricultural activities have been taking place since the end of the 19th century. We choose to study two quite relevant crops, because we know that we have at hand 3-4 biophysical models able to simulate these ones and that they are mostly cultivated with high level technologies in irrigated conditions. These facts allow us to use the concept of potential yields in order to assess climate change impacts on these crops – if we choose a crop like sugarcane then we would have to calculate rainfed yields, which are much more complicated to estimate. Having selected those irrigated crops we then claim – and are granted – the right to undertake assessment of the water resources sector. In doing all this analysis we already know that we have enough historical climate data for the region at hand – as you cannot undertake any assessment at all without having a minimal amount of climate data available.

Then they ask us to study an additional specific crop because of its importance in the national food balance. After some very detailed discussions we accept this reluctantly – because we know that we have at least one impact model able to simulate (with some limitations) the development and growth of this crop. The problem here is that we have no real experience simulating this crop and we are insecure about being able to do a satisfactory analysis of its expected impacts. In making such assessment, a number of ethical considerations are involved, and we must avoid taking a position that will jeopardize our credibility and mislead our higher authorities.

In relation to livestock production, we then choose a different one instead of cattle, because we have recently finished an assessment on cattle production in our area, and because we just have acquired one usable model for this other livestock production that we want to use for the first time in our country.

Now the first step is completed. To describe it has been easy, even if it took several national specialists, holding 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 conduct a climate change impact assessment. But since an impact assessment must always be done – because we can't allow our decision makers to work in darkness – 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. In reality, it is almost impossible to build such a dataset in developing countries. That's why, for practical purposes, often you will have to use less complete climate datasets comprising a lesser number of years (10, 15, 20…) and forget daily values in order to work with mean monthly values instead. There are many possible solutions, covered in Chapters 1 and 3 of the Workbook (Rivero, 2008).

EXAMPLE 1.2*: In the region selected, we know that we have three different meteorological stations. But we discovered that we could make a reference representative climate dataset – meaning not complete – of the 1961-1990 period, consisting of monthly means for all climate variables needed except global solar radiation. We also realized that we could build additionally a complete daily dataset for the 1994 -2009 period. Global solar radiation – never measured in these stations – was estimated using an empirical approach based on maximum and minimum temperatures. So we built two completely independent and different 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 take monthly values as inputs, and other models where this is not possible at all. Refer to Chapter 3 of the Workbook.

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

THIRD STEP: Choosing suitable impact models

In every assessment you will have to use one or many different impact models. An impact model of something could be defined as one model whose final outputs and results vary when you specify different climate conditions as inputs. Generally, impact models used in agricultural assessments give different outputs even for the same climate as input, if you specify different crops, varieties, soils and management conditions. There are many different kinds of impact models, depending on the assessment it is intended to do but, in our case, it necessarily should depend explicitly on one or many climate variables. In our team's point of view, we strongly recommend the use of crop models based on plant physiology, animal behavior or response to climate conditions based on animal physiology knowledge, and the use of climate indexes and laws of physical climatology as impact models in agricultural and water resources sector. Different impact models are discussed in Chapters 2, 3, 5, 6, 7, 8 and 9 of the Workbook.

One must realize, however, that there are crops or aspects of food production for which there are no available models at all. In such cases you will have to use "ad hoc" procedures even if that implies changing the usual relevant parameters. As an example, we were able to stop planting a given crop in some part 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... and 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 install kilometers of irrigation tubes and dedicate a water source in order to irrigate the crop during most of the year, they decided not to plant. Criteria such as this one could be used also in hypothetical situations expected in future climates because this requisite – not fulfilled today in current climate conditions – could become true in a future climate ,making the cultivation of that crop possible in locations where it wasn't before. Obviously, this rule of thumb could also occur in a contrary direction, making impossible tomorrow what is possible today.

EXAMPLE 1.3*: As we have no previous experience with the third crop selected, we decided to use our most simple and intuitive model in order to study it, that is, WOFOST 4.1. This model can work with only monthly climate data as input, so it was consistent with one of our reference climate datasets. See Chapters 3 and 9 of the Workbook.*

For the other two crops, we had two well-known models applicable those crops, so we used both models. One of them is WOFOST 7.1.2, a model that can use 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.

Livestock production cannot rely on a crop model of course, so we based our hopes in estimating values of the Temperature – Humidity Index (THI) and relating it to different parameters of the selected livestock's behavior and production. Additionally, we used a specific livestock model available on Internet. Please refer to Chapter 8 of the Workbook, on livestock 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 the Budyko's approach. See Chapters 2 and 6 of the Workbook.

FOURTH STEP: Applying impact models and tools to reference climate dataset

Now you must apply all your selected impact models and tools to the reference climate datasets. This must always be done in order to obtain a set of simulated response of crop, animals and water resources in current (reference) climate conditions. First of all, you may discover with these sophisticated tools many behavioral traits of crops, animals and water resources that have not been noticed before, even by very specialized agricultural people.

Second you must calibrate somewhat – comparing with real data and farmers' observations - 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.

Thirdly, you will need a simulated set of current climate responses, in order to study later how these responses will change in different foreseen futures climates (climate change scenarios) during the 21st century.

This third 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 the previous discussed steps constitute already a scientific study that you may apply in many different agro-meteorological services.

EXAMPLE 1.4: *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 the results will be released to a wider audience in 2012.*

FIFTH STEP: Creating future climate change scenarios

An assessment of climate change impact on anything cannot be done 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 estimates 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 used to call Bultot's scenarios. Climate change scenarios can also be borrowed from foreign sources, as there are a lot of such kind 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 and because they allow 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 (GCM) and Regional Climate Models (RCM) 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 it may be 50 by 50 or 25 by 25 kilometers in size. One 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 into your country and able to differentiate plains from mountainous land or coastal 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 out in the Workbook, in part because the scenarios building processes are normally very specific to meteorological institutions and climate research centers. Generally, climate change scenarios are built by a separate research team from the impact assessment team. The partial overlap of these two different teams in our country could be considered unusual, and not as 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 current reference climate observed variables 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 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 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 yet published and will not 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 for 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 depend not only on climate change, but also on other 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 selected for one or other purpose, depending on the nature of the research, because what is important for someone could be irrelevant for another person. The process itself will help you with this problem, because you can select as relevant any parameter that reflects a significant variation with climate change without even knowing if 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 livestock production they may consist of milk, meat or egg production, thermal stress on livestock and related parameters. In the case of water resources, relevant parameters could be: duration and magnitude of recharge periods, total annual runoff, and climatic indexes from which aridity and desertification processes can be inferred. Total area and per capita food production could be also very relevant parameters, but their assessment would imply some kind of aggregation of results obtained in different localities or one cross-sectoral 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 conducted in the selected region for all previously selected issues. Results will be available next year, and reflected important negative impacts in all the four climate change scenarios. 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 the Budyko's approach and climate change scenarios created with the MAGICC/SCENGEN 4.1 system. This allowed us to obtain the expected future evolution of aridity and water availability for the whole country using different climate indexes. In parallel to this, we also obtained the expected future evolution of potential biomass density and net primary productivity. Results were already presented and published this year in an international climate change congress, regretfully in Spanish (Rivero and Rivero, 2011a and b). You con find 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, adaptations 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 modifying the current pattern of agricultural activities by changing the current planting season under rainfed agriculture, or as complex as changing agricultural management by moving from rainfed agriculture to irrigated agriculture. It is advisable not to reject initially any – apparently science fictional - idea never heard before without going through the next step, devised to assess the feasibility of that option and confirm its possible benefits by any conceivable means. Adaptation options could come from sectors apparently unrelated to actual agricultural practices, including some very shocking options, such as abandoning agriculture altogether and focusing instead other sectors, such as tourism. At this stage of our work, activities such as brainstorming could generate some very innovative options, in a context much wider than just the agricultural sector.

As the very existence of suitable adaptations options is being questioned from the outset of this process, that is one very important reason to keep working hard on the subject of global mitigation activities, in order to put a well-defined limit on the magnitude of climate change, so that this very menacing issue doesn't reach a magnitude large enough to completely disrupt our civilization as we know it.

It must be understood that any conceivable adaptation option will bring its own additional, and often unforeseen, impacts on a context broader than just agriculture. 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 cannot be assessed by impact teams in which only agriculture and climatological experts are adequately represented.

A preliminary list of simple adaptations options could include:

- Changing planting dates and crop calendar.

- Changing crop and livestock production management related with irrigation procedures, application of fertilizers, integrated plant protection strategies, development and introduction of new crops or crop varieties, management of thermal stress on livestock production, water conservation procedures and many others.

- Changing the spatial pattern of agricultural activities (crop regionalization) by shifting current areas for specific crops to new, more suitable, areas elsewhere in the country (such as planting potatoes at higher altitudes over sea level, from low-lying valleys to higher level plateau or high terrain in order to avoid the negative impact of high temperatures).

But one can never be so optimistic as to think that simple solutions will be always available for such a complex problem as the significant change in climate behavior. It is very easy to write on paper an adaptation option 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 for producing a new variety able to withstand new foreseen temperatures and soil water availability because of climate change. One could hope 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. Experience shows us that introducing genetic engineering as an adaptation option in food production is like opening Pandora's Box – in suggesting such an adaptation option you will be facing a number of scientific, technological and ethical issues.

EXAMPLE 1.7: *Recognizing that far-reaching adaptation strategies in our case study will require a set of deeper multidisciplinary and integrated impact assessments, current adaptations options discussed were mostly simple and general, such as:*

- *Changing current agricultural development practices without taking into consideration climate circumstances and climate change, by introducing what has come to be known as operational agro-meteorology and response farming.*

- *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 livestock.*

- *Introducing new irrigation technologies, leading to a more efficient use of available water for agricultural purposes.*

EIGHTH STEP: Assessing adaptation options

The impact team must devise some ways to quantitatively estimate the expected results of proposed adaptations options before they are actually applied in the fields. Adaptation is always a risky and costly process in which we can't afford to invest money, resources and efforts without having considerable certainty about benefits that will be derived from executing them. In principle, the expected impact of adaptations options should be addressed by implementing them in a simulated environment and seeing the predictions of the same impact models used in the vulnerability assessment in those new – supposedly adapted – conditions (Benioff et al., 1996).

But obviously running the impact models with adaptations options taken into account will not necessarily allow us to estimate second order impacts of adaptation in aspects outside the range of what can currently be simulated by the given models, which could be called "collateral damage". Additionally, the range of hypothetically possible adaptations options will be much wider than the range of options that can be realistically simulated by the impact models previously used in the assessment. A different set of simulation models – containing the subset of impacts 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 be called a top-down approach in this document, the process of assessing adaptations options would be much easier if the results of a 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. 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 such an assessment, is a formidable task requiring authors, co-authors and editors, plus a support team of collaborators. Such a report would easily extend for hundreds of pages, 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 remain unpublished – but will be of very little use for stakeholders and decision-makers. A summary report of twenty pages could cover 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 a brief communication of a few pages describing objectives, results and recommendations would be easy to understand for stakeholders and decision-makers.

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

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