Report on methodology of vulnerability analysis

Gianni Bellocchi, Romain Lardy, Jean-François Soussana

AnimalChange

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

SEVENTH FRAMEWORK PROGRAMME

Grant agreement number: FP7- 266018

DELIVERABLE 5.2

Deliverable title: Report on methodology of vulnerability analysis

Abstract: The goal of task 5.2 of AnimalChange project is to use approaches (developed by task 15.3) to assess vulnerability to climate change of livestock production systems (simulated by task 5.1).

Due date of deliverable: M18 Actual submission date: M19

Start date of the project: March 1st, 2011 Duration: 48 months

Organisation name of lead contractor: INRA

Authors: Gianni Bellocchi, Romain Lardy and Jean-François-Soussana

Revision: V1

Dissemination level: PU

Release	Date	Reason of change	Status	Distribution

Table of Contents

1. Introduction

The goal of task 5.2 of AnimalChange project is to use approaches (developed by task 15.3) to assess vulnerability to climate change of livestock production systems simulated by task 5.1 across the three regions (after D5.1):

1. Europe
2. Regions in Africa : South Africa, and, if possible, Senegal and Tunisia
3. Regions in Brazil

Models from WP3 and WP4 are meant to be up-scaled to the scale of the project regions in WP5 using datasets and scenarios from WP2 for climate, soil, land-use, crop and pasture management, animal production and manure management. Projections in WP5 will be consistent with baseline and CO_2 stabilization scenarios produced for IPCC AR5.

In task 5.2, the vulnerability to climate change of pastures, arable feed crops and animal production will be assessed for Europe and study regions in Africa and South-America. The climate is composed of both the mean climate signal (e.g. average annual temperature cycle) and its temporal variability, which also includes the occurrence and magnitude of extreme events. As climate change results in both changes in the mean climate signal (e.g. average annual temperature) and its temporal variability (including the occurrence and magnitude of extreme events), in a climate change context vulnerability is defined as "*the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the **sensitivity** of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects), **adaptive capacity** (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of **exposure** of the system to climatic hazards*" (IPCC, 2001). Probabilistic measures and a set of indicators of vulnerability, accounting for sensitivity, exposure and adaptive capacity will be computed and assessed. The procedures for vulnerability assessment described in this report reflect the methodology outlined by Lardy et al. (2011, 2012), and integrates principles from the probabilistic assessment of vulnerability as elaborated by van Oijen (2012) in the framework of FP7-EU CARBO-Extreme project (http://www.carbo-extreme.eu).

2. Conceptual framework for vulnerability assessment

Below is a list of concepts commonly used and providing a framework for vulnerability assessments. It follows the diagram of Figure 1, which represents the essential components of vulnerability to climate changes.

1. **HAZARD.** An **hazard** is a factor that can cause damage. Any environmental variable constitutes a hazard if too low or too high for optimal ecosystem performance. It becomes hazardous if it is in the range of values that generate negative impacts under on the ecosystem variable under study; According to an "external" definition of hazardous conditions, they are known before the simulation results are produced,

e.g. by inspecting definition of extreme events commonly used in the literature; According to an “internal” definition, hazardous ranges of environmental variables are derived from the modelling results.

2. **EXPOSURE.** The exposure is the set of shocks and disturbances to which the system is subject with a certain probability. In our case, it is the degree and nature of environmental change (e.g. long periods under high temperature) to which the ecosystem is subject. Exposure is actually influenced by global change and climate variability, GHG concentrations and **non-climatic factors** (set of environmental, political, socio-economic, demographic and technical factors). Non-climatic factors are defined by the **non-climatic scenarios** (e.g. maize price scenarios).
3. **SENSITIVITY.** The sensitivity (also said **susceptibility**) is the degree to which a system is affected, positively or negatively, by climatic stimuli. The sensitivity of a system becomes particularly important when substantial changes in the system arises for low levels of climatic changes, whereas for strong stimuli (such as extreme events), the system recovery properties predominate, namely the **amplitude** and the **elasticity**. **Amplitude**, also called **ecological resilience**, is the maximum tolerated perturbation before changing the system so much that we are not able to come back to its reference state. It corresponds to the internal adaptation capacity of a system, defined as the recovery potential of an ecosystem (De Lange et al., 2010). The recovery rate against small perturbations ("**engineering resilience**”, Holling, 1996), defined as the rate of return to the reference state (or dynamic) after a temporary disturbance (Grimm and Wissel, 1997) is also called **elasticity**. Together, sensitivity, ecological resilience and elasticity represent the ecosystem **stability**, and are mainly influenced by non-climatic factors.
4. **IMPACTS.** Impacts are principally driven by exposure of the system to climatic pressure and its stability properties. Among the impacts, we can distinguish **potential impacts** and **residual impacts**, which are all the impacts resulting from climate change before or after strategy application (i.e. adaptations or mitigations), respectively. The vulnerability is sometimes seen as the residual impacts of climate change after adaptation measures have been taken (e.g. FAO, 1996).
5. **ADAPTIVE CAPACITY.** The concept of residual impacts uses the notion of **adaptive capacity**, i.e. the system ability to change in order to be less vulnerable. In the climate change context, it can be defined as the system ability to adjust to climate change (including climate variability and extreme phenomena), to moderate potential damages, to take advantage of opportunities or to cope with the consequences. Adaptive capacity is a direct function of non-climatic factors. **Vulnerability** is a function of impacts and adaptive capacity. Within the adaptation (and mitigation) capacity, we can distinguish **potential adaptation capacity** and **real adaptation capacity**, whether it is limited or not by non-climatic factors.
6. **ADAPTATION AND MITIGATION STRATEGIES. Mitigation** consists in reducing the sources or enhancing the sinks of GHG (Füssel and Klein, 2006), whereas **adaptation** policy is to reduce the negative and inevitable effects of climate change. The major prerequisite for such strategies is the adequacy of resources needed to implement them. Historically, mitigation has received more attention because, on one side, mitigation reduces the impact on the integrity of all the systems potentially sensitive to climate change. On the other hand, the potential of adaptation policies is very limited for some systems. For a more accurate comparison between adaptation and mitigation, the reader is referred to (Füssel and Klein, 2006). These two, yet different but intimately linked strategies, can influence a number of factors. Adaptation seeks primarily to influence stability, non-climatic factors and system exposure and thus the impact of climate change on specific systems, whereas mitigation mainly impacts the GHG concentrations in the atmosphere through reduction in emissions.

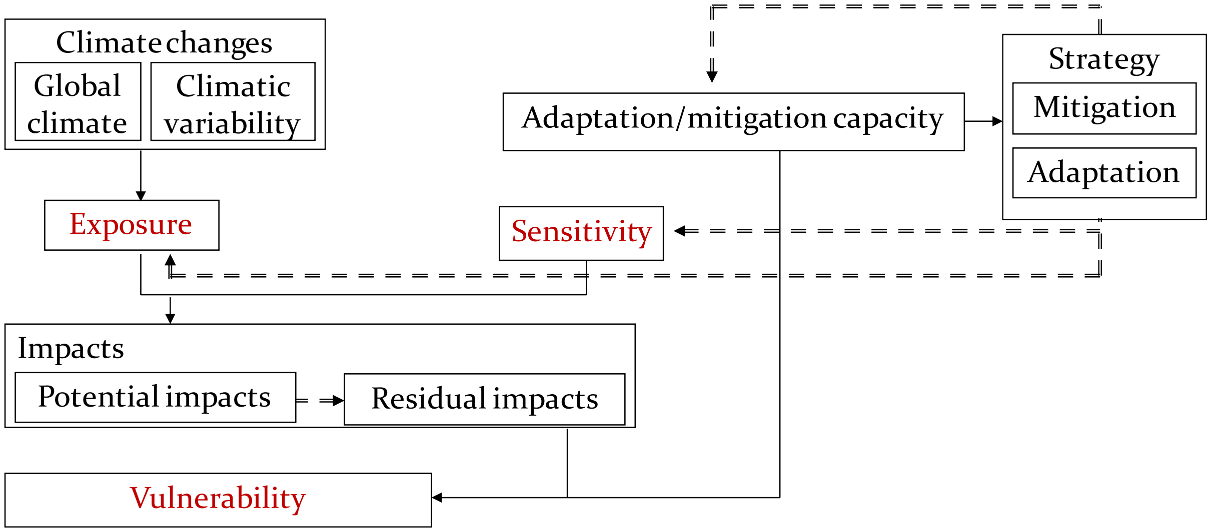

Figure 1. Conceptualization of vulnerability to climate change, after Lardy et al. (2012). Dashed arrows represent the feedbacks of mitigation and adaptation strategies onto climate change impacts.

3. Probabilistic vulnerability assessment

Vulnerability is defined in such a way that it includes both the elements of an impact assessment (i.e. sensitivity of a system to a hazard and exposure to hazardous conditions), and adaptive capacity to cope with potential impacts of climate change. In the framework of FP7 CarboExtreme project, a probabilistic framework has been developed for application to ecosystems. This approach is based on a probabilistic risk assessment, which combines probability distribution functions (PDF) of climatic hazards (**exposure**) and of ecosystem processes **sensitivity** to those hazards. The PDF of climate change **impact** is then calculated from the probability of sensitivity conditional to exposure. In this way, the framework includes both the effects of variability (in climate) and of uncertainty (in model parameters and structure). **Adaptation** can further be considered to derive the probability distribution function of residual impacts after adaptation, which defines a probabilistic **vulnerability**.

The system is less vulnerable to climate when less exposed to hazardous events and less sensitive to them. Vulnerability analysis is thus the result of a three-step procedure in which exposure, sensitivity and impact are assessed (examples below). The baseline is given by assessments without taking adaptation/mitigation measures (potential impact assessment). However, since vulnerability of an ecosystem to climate change is less when farmers or society are able to adapt to changes, it is also important to assess and compare the vulnerability taking into account adaptive capacity (residual impact assessment). Adaptation/mitigation strategies may aim at decreasing ecosystem sensitivity, changing the threshold of damage, or reducing exposure. For instance, reduction of sensitivity and exposure to drought may be obtained by shifting management practices such as using drip irrigation and taking measures to increase soil water retention. Shifting to more drought resistant crops or dig groundwater wells are also potential measures in the long-term.

1. Exposure

There is an interest to quantify the probability for ecosystems to incur potentially hazardous climate events. This can be done by quantifying precipitation and temperature hazardous events via agro-climatic metrics. The climate hazard can be appreciated by analyzing statistics of high values (e.g. 95th percentile) The example below (Fig. 2) is generated from the probability distribution of two key agro-climatic indices (length of dry spell, mean number of heat waves over May-September) for different time slices and for an ensemble of climate models in Europe.

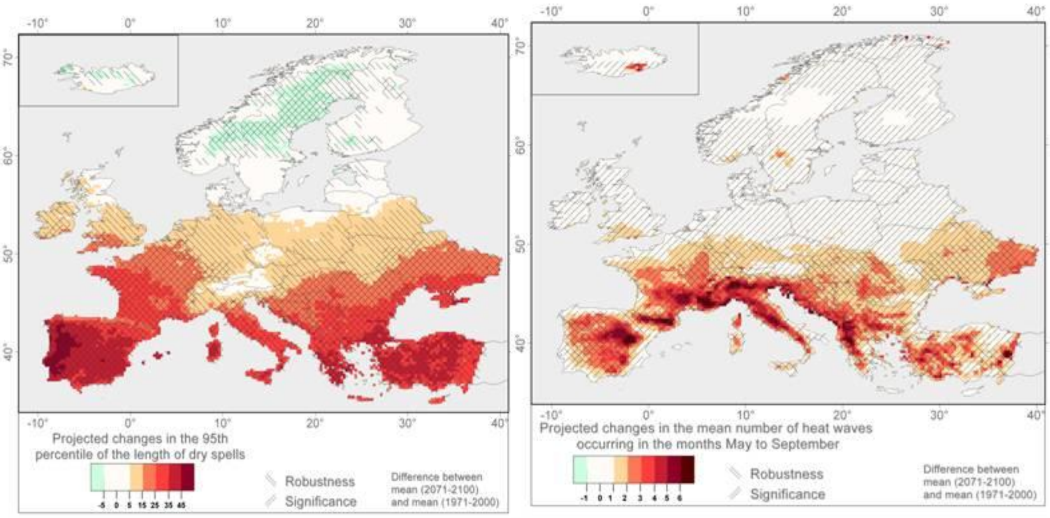

Figure 2. Projected changes of the differences in the 95th percentile of two climatic variables (left: length of dry spells; right: mean number of heat waves) from two time slices (past: 1971-2000; future: 2071-2100), as generated by an ensemble of models in Europe (from the EC-ENSEMBLES project, CMIP3) ///// Significant (P<0.05) \\\\\ Robust (>2 models out of 3)

2. Sensitivity

The sensitivity of an ecosystem process to a given change in a climatic variable may be evaluated through modeling. For instance, pasture production sensitivity to hazardous climatic conditions can be modeled by:

- i) Defining hazard conditions, e.g. low precipitation values. For instance, hazardous conditions may be defined as precipitation below the 25th percentile ;
- ii) Studying simulated pasture production in response to the hazardous conditions. For instance, simulated variations in pasture production between future (e.g. 2079-2100) and past (e.g. 1999-2010) climate conditions associated with hazardous low precipitation values can be calculated.

Importantly, the sensitivity of the studied variable to a given climatic hazard may vary over time as a direct result of climate change (e.g. soil and vegetation degradation may result in a higher sensitivity to a low precipitation event).

3. Impact

Multiple scenarios provide us with a range of possible changes in climate (i.e. exposure) and allow us to assess the response of ecosystems and changes in the services they provide (i.e. potential impacts). Standard analyses target mean annual impacts (e.g. yield levels) by comparing 30-year time slices of future and past conditions. Low and high percentiles (e.g. 10th and 90th) are also selected as options to represent impacts associated with worse and best years. They can be extracted from distribution functions as in the example of Fig. 3 which shows an increased risk of low summer milk production towards the end of the century compared to current conditions (for a pasture site in eastern France). This statistical approach shows that the 90th percentile for daily summer milk production per unit pasture area (kg m^{-2}) drops from 0.025 to 0.010 g at the end of the century compared to the reference time period.

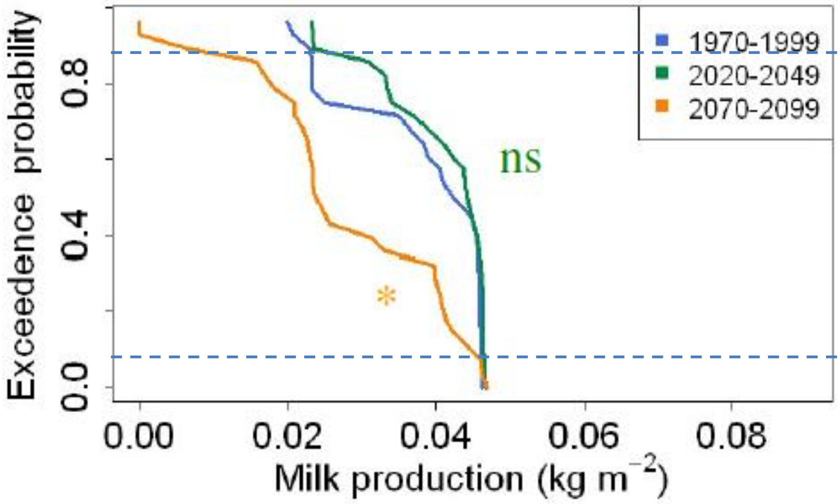

Figure 3. Example of exceedence probabilities for an impact variable (summer milk production as affected by climate change) for a pasture site in eastern France under three 30-year time slices. Simulations were run with the PASIM model assuming a constant management during the course of the century. Horizontal lines indicate the 10th (bottom) and the 90th (top) percentile, respectively. (Graux et al., Agricultural Forest Meteorology, in press).

Changes over time can be studied in this way for a given site. However, when comparing sites across regions, relative changes – e.g. (future mean yield – past mean yield) / past mean yield – need to be calculated in order to scale future changes in relation to their current value.

4. Vulnerability indices

A number of quantitative vulnerability indices have been used in the literature (Table 1). Importantly, these indices simply correspond to impacts when adaptation is not considered.

Table 1. Summary of vulnerability indices. *W* is the state variable (e.g. productivity), W_0 is the productivity threshold, *n* is the number of elements (years), *q* is the number of elements below the threshold value. When calculated, the indices are weighted by exposure.

Index	Formulation	Notes
Proportional vulnerability (Foster et al., 1984)	$V_0 = \frac{q}{n}$	It corresponds to the number of vulnerable individuals (years) in a population of years.
Vulnerability gap (Foster et al., 1984)	$V_1 = \frac{1}{n}\left[\sum_{i=1}^{q}\frac{(W_0 - W_i)}{W_0}\right]$	It represents mean deficit in vulnerable individuals (years).
Vulnerability severity (Foster et al., 1984)	$V_2 = \frac{1}{n}\left[\sum_{i=1}^{q}\left(\frac{(W_0 - W_i)}{W_0}\right)^2\right]$	The distance to threshold is used as a weight. More weight is given to the most vulnerable cases.
Most vulnerable individual	$V_\infty = 1 - \frac{\min_i W_i}{W_0}$	It is the relative distance to threshold of the most vulnerable case.
Luers et al. (2003)	$V_L = f\left(\frac{\lvert\partial W/\partial X\rvert}{W/W_0}\right)$	The coefficient of variation is used for quantifying the sensitivity of the system.

Vulnerability is a relative notion, and absolute values attached to a vulnerability index are not meaningful (Downing et al., 2001). Mostly, defining the vulnerability of a system requires identifying a threshold below or above which the system is considered to be damaged.

5. Comparing vulnerability assessment methodologies

In order to make progress, a range of possibilities have been explored through a step by step approach. Lardy et al. (2011) have used this approach to derive response surfaces of pasture model sensitivity to a range of climatic conditions and according to a range of simulation designs:

- The first design ("simple") consists in merely simulating the pasture system over 30 years time slices for a given management and under fixed atmospheric CO_2 concentration.
- In the second design ("climate uncertainties"), a bootstrap method was used to check that the occurrence of individual climatic years is a random event (low correlation between successive years).
- In the third design ('Extreme events'), the frequency of hazardous conditions (i.e. dry spells) was artificially increased in the 30-year time series.
- In the fourth design ('Management'), uncertainties in management were introduced by considering a Gaussian distribution for mowing dates.

Table 2. Vulnerability indices (see Table 1) calculated with different designs for 'near future' (NF: 2020-2049) and 'far future' (FF: 2070-2099). The values are relative to the "reference period" (RP: 1975-2004). The higher the index, the more vulnerable the system is (Lardy et al., 2012). An upland permanent pasture in France was simulated (ModVege model, Jouven et al., 2006a, b) for three time slices of 30 years each. Future climate projections are based on the A1B emission scenario.

Design \ Index	Most vulnerable individual		Luers' index		Proportional vulnerability		Vulnerability gap		Vulnerability severity	
	NF	FF	NF	FF	NF	FF	NF	FF	NF	FF
Simple	1.62	2.76	1.66	2.23	2.13	2.63	3.14	7.64	4.49	20.37
Climate	1.57	3.00	1.42	2.33	1.92	2.58	2.98	8.35	4.38	23.58
Extreme events	1.62	2.77	1.67	2.22	2.16	2.64	3.16	7.64	4.48	20.22
Management	1.45	2.45	1.67	2.19	2.06	2.55	3.08	7.42	4.12	18.65

Vulnerability indices were calculated for each design (Table 3). As expected, given the constant CO_2 concentration, climate change had negative impacts on the pasture system studied (thereby changing the vulnerability index). This is due to decreased grassland productivity, though with slightly reduced inter-annual variability. Simulations accounting for extreme events frequency uncertainties did not show differences compared with the "simple" design, probably due to the low responsiveness of the model to extreme events. Accounting for climate years order uncertainties (design 2) globally increased vulnerability values. This shows that uncertainties on climate scenarios, climate models and regionalization techniques should be accounted in climate change vulnerability assessment studies. Whatever index is considered, uncertainties on management (i.e. mowing dates) tend to reduce vulnerability. This means that the sensitivity and the uncertainties on cutting dates should be accounted for in an impact assessment, but also when looking for adaptation options.

Including a range of indices in vulnerability assessment is important because each of them contains complementary information. For instance, the most vulnerable individual index informs us that the productivity of the most vulnerable year is expected to be up to three times lower in the far future than at present (design 2), whereas vulnerability severity informs about how severely the system is expected to be damaged. At the same time, thanks to the vulnerability gap, we know that average missing biomass for vulnerable cases may increase up to eight times, whereas the number of vulnerable cases increases by 2 to 2.5 for NF and FF period, respectively (proportional vulnerability). The Luers' index (calculated here using the coefficient of variation as sensitivity measure) is a kind of average index, which combines information on global productivity with the variability of the system. It also has the advantage of being threshold-independent, and as such does not require decisions regarding thresholds.

6. Outputs from models

The required variables for each simulation in task 5.1 will depend on the model used, as models are able to simulate different kinds of outputs. Table 4 gives the main model outputs expected with their units and requested time step (after D5.1).

Table 3. Simulated output variables (after D5.1).

Category	Variable	Unit	Time step
GHG fluxes	Net CO_2 flux	g C m^{-2} dt	monthly
	Net biome productivity	g C m^{-2} dt	monthly
	Gross primary productivity	g C m^{-2} dt	Monthly
	Ecosystem respiration	g C m^{-2} dt	Monthly
	Net primary productivity	g C m^{-2} dt	Monthly
	Methane emission	g C m^{-2} dt	Monthly
	N_2O emission	g C m^{-2} dt	Monthly
Productivity	Grassland production	g C m^{-2} dt	Yearly
	Crop production	g C m^{-2} dt	Yearly
	Animal production (per animal type)	kg live weight m^{-2} dt	Yearly
	Milk production	g C m^{-2} dt	Yearly
Carbon stocks	Total soil carbon	g C m^{-2}	Yearly
	Total biomass	g C m^{-2}	Yearly
Automatic management	Mean animal density	LSU ha^{-1}	Yearly
	Fertilizer input	g N m^{-2} $year^{-1}$	Yearly
	Irrigation	mm $year^{-1}$	Yearly
	Number of cuts	---	Yearly

A vulnerability analysis may be virtually implemented based on any impact variable. Application in the AnimalChange project will be limited to productivity outputs at the scale of simulation defined by task 5.1. Maps of vulnerability indices will be generated, with the complement of probability distributions of production losses at selected areas. Moreover, the comparison of multiple climate and impact models will provide an estimate of the uncertainty associated with using alternative modelling solutions.

7. Implementation

The implementation of vulnerability assessment will be grounded to the general definitions of this deliverable. Impact variables, indicators and metrics to be analysed will be defined in detail via an exchange with involved partners (INRA, CEA DLO, ILRI, EMBRAPA, IIASA, UP, FAO).

A core of ecosystem models (PaSim, ORCHIDEE, GRange) may be selected for a set of initial analyses, for extension to analyses with models at different scales (e.g. GLOBIOM). Impact variables will be selected out of the list in Table 3, with primary focus on ecosystem productivity. To characterize climate change hazards, an initial set of climatic hazard indicators will include the three indicators in Table 4. Dry spells are based on precipitation only and are indicative prolonged periods of dry weather. However, they are not as severe as a drought and may appear interspersed with occasional large rain events (>100 mm). Heat waves address the issue of prolonged periods of excessively hot weather. The aridity index combines temperature and precipitation values. An altered pattern of these two climatic variables may mean an expansion of aridity conditions. This metric indicates the relative dryness of an area and thus summarises the agricultural production potential that can be attained.

Table 4. Short list of hazard indicators. *P*: daily precipitation (mm), T_{max}, maximum daily temperature, P_Y, yearly precipitation total (°C), T_Y, mean annual temperature (°C), p_a=precipitation total of the driest month, T_a, mean temperature of the driest month (°C).

Indicator	Quantile	Metric	Reference
Dry spell length	25 %	Maximum number of consecutive days in a year with $P = 0$	after Barnett et al. (2006)
Number of heat waves	75 %	Number of minimum seven consecutive days when T_{max} > average T_{max} (baseline period) + 3 °C	after Barnett et al. (2006)
De Martonne-Gottmann aridity index (*b*)	75 %	$b = \frac{1}{2} \cdot \left(\frac{P_Y}{T_Y + 10} + 12 \cdot \frac{p_a}{T_a + 10} \right)$	De Martonne (1942)*

* *b* < 5: extreme aridity, 5 ≤ *b* ≤ 14: aridity, 15 ≤ *b* ≤ 19: semi-aridity, 20 ≤ *b* ≤ 29: sub-humidity, 30 ≤ *b* ≤ 59: humidity, *b* > 59: strong humidity.

Sensitivity will be assessed against low precipitation (<25th percentile) and high mean annual (or seasonal) temperature (>75th percentile) values. Aridity will also be assessed against high values (>75th percentile).

Synthetic measures (indices) for vulnerability assessment will also be provided as a complement to probabilistic assessment of sensitivity and exposure. This will help communicate the results of vulnerability assessment to stakeholders. As a basis, the index by Luers et al. 2003 (Table 1) will be calculated on 30-year time slices of future climate relative to baseline, according to ‘simple’ evaluation strategy (Table 2). Other options (alternative indices and evaluation strategies) will be considered as options for specific use by some of the modeling teams.

The procedure will be first run without either adaptation or mitigation, and will be repeated by including adaptation/mitigation options (interaction with WP8).

This process will be basic to both training session (MS63: Numerical methods for project vulnerability analyses with guidelines for use, scheduled month 24) and guidelines (D15.3: Numerical methods for project vulnerability analyses with guidelines for use, scheduled month 24) for vulnerability assessment.

8. References

Barnett, C., Hossel, J., Perry, M., Procter, C., Hughes, G., 2006. A handbook of climate trends across Scotland. Scotland and Northern Ireland Forum for Environmental Research, SNIFFER Project CC03, Edinburgh, United Kingdom.

De Lange, H.J., Sala, S., Vighi, M., Faber, J.H., 2010. Ecological vulnerability in risk assessment – A review and perspectives. Science of The Total Environment, 408, 3871-3879.

De Martonne, E., 1942. Nouvelle carte mondiale de l'indice d'aridité. Annales de Géographie, 51, 242-250. (in French)

Downing, T.E., Butterfield, R., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y., Stephen, L., 2001. Vulnerability indices: climate change impacts and adaptation. UNEP Policy Series, UNEP, Nairobi., 91 pp.

FAO, 1996. Global climate change and agricultural production. Direct and indirect effects of changing hydrological, pedological and plant physiological processes. John Wiley & Sons Ltd., Chichester, United Kingdom.

Foster, J., Greer, J., Thorbecke, E., 1984. A class of decomposable poverty measures. Econometrica, 52, 761-766.

Füssel, H.M., Klein, R.J.T., 2006. Climate change vulnerability assessments: an evolution of conceptual thinking, Climatic Change, 75, 301-329.

Grimm, V., Wissel, C., 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. Oecologia, 109, 323–334.

Holling, C.S., 1996. Engineering resilience vs. ecological resilience. Engineering within ecological constraints. National Academy, Washington, DC, 31-43.

IPCC, 2001. *Impacts, adaptation, and vulnerability climate change 2001.Third Assessment Report of the Intergovernmental Panel on Climate Change*. University Press, Cambridge, United Kingdom.

Jouven, M., Carrere, P., Baumont, R., 2006a. Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 1. Model description". Grass and Forage Science, 61, 112-124.

Jouven, M., Carrere, P., Baumont, R., 2006b. Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 2. Model evaluation. Grass and Forage Science, 61, 125-133.

Kleijnen, J.P.C., Sanchez, S.M., Lucas, T.W., Cioppa, T.M., 2005. State-of-the-art review: a user's guide to the brave new world of designing simulation experiments". INFORMS Journal on Computing, 17, 263-289.

Lardy R., Bellocchi G., Bachelet B., Hill D.R.C., 2011. Climate change vulnerability assessment with constrained design of experiments, using a model driven engineering approach. In: Novais P., Machado J., Analide C., Abelhapp A. (Eds.), The European Simulation and Modelling Conference ESM®'2011, 24-26 October, Guimarães, Portugal, 354-446.

Lardy R., Graux A.-I., Bachelet B., Hill D.R.C., Bellocchi G., 2012. Steady-state soil organic matter approximation model: application to the Pasture Simulation Model. In: Seppelt R., Voinov A.A., Lange S., Bankamp D. (Eds.), 2012 International Congress on Environmental Modelling and Software, Sixth Biennial Meeting, Leipzig, Germany.

Luers, A.L., Lobell, D.B., Sklar, L.S., Addams, C.L., Matson, P.A., 2003. A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. Global Environmental Change, 13, 255-267.

Nakićenović, N., 2000. Greenhouse gas emissions scenarios. Technological Forecasting and Social Change, 65, 149-166.

Van Oijen, M., 2012. A protocol for probabilistic vulnerability assessment in project Carbo-Extreme. D7.2 - Agreed guidelines on the methodology of vulnerability analysis. Available to project members through http://www.carbo-extreme.eu.