Impact of Climate Change on Cereal Market and Food Security in Sudan: Stochastic Approach and CGE Model

Sassi M.[1] and Cardaci A.[1]

[1] Department of Economics and Management, University of Pavia, Pavia, Italy
msassi@eco.unipv.it

Summary

The paper aims at analysing the impact of the likely change in rainfall on food availability and access to food in Sudan. The empirical investigation is based on an integrated approach consisting of a stochastic method and CGE model. The former provides the likely changes in sorghum, millet and wheat productivity and their probability of occurrence according to rainfall predictions based on historical data. These results are at the basis of the shocks simulated in a standard CGE model augmented with a stochastic component. Achievements underline the negative impact on the two dimensions of food security taken into consideration, mainly due to a reduction in cereal supply, a marked cereal inflation pressure and income contraction; the grater negative effect on the poorest households; and a deterioration of the economic performance of the country. In this context, the paper stresses a strong interconnection among climate change, poverty and food insecurity and thus the need for an integrated policy-making approach.

Impact of Climate Change on Cereal Market and Food Security in Sudan: Stochastic Approach and CGE Model

Sassi M.[1] and Cardaci A.[1]

[1] Department of Economics and Management, University of Pavia, Pavia, Italy
msassi@eco.unipv.it

1. INTRODUCTION

The evidence from the literature agrees on three points: there is a high probability of significant changes in global climate (Ito et al., 2010; IPCC, 2007); the state of environment will continue to deteriorate if the right actions are not taken (Torres, 2008); and the relative impacts of climate change are greater in low-income countries (Tol, 2010). These latter are more vulnerable due to several factors, among which there are their location in tropical zones of the equatorial area, increasing temperatures that already affect production in sectors like agriculture, their lower adaptation and institutional capacity.

The recently developed empirical investigations focus on specific aspects of the effect of climate change. The major topics concern the impact on agriculture and forestry, water resources, coastal zones, energy consumption, air quality and human health and welfare (Tol, 2010). Little attention is given to food security, particularly in Sub-Saharan Africa (Thompson et al., 2010). This paper addresses this topic, focusing on the impact of rainfall.

Changes in the precipitation patterns are one of the dimensions of climate change. This is of great importance in developing countries, where the rain-fed agriculture is still a dominant economic activity. Also in this respect, Sub-Saharan Africa shows a higher vulnerability compared to other developing areas. For example, in the continent, more than 95 per cent of the farmed land is rain-fed, whereas this is almost 90 per cent in Latin America, about 60 per cent in South Asia, 65 per cent in East Asia, and 75 per cent in the Near East and North Africa (Huho, 2011). This sector also constitutes the livelihood base for a vast majority of inhabitants and, for this reason, it plays a crucial role in food security (Wani et al., 2009).

The paper focuses on Sudan, one of the poorest countries in the world, and with more than a quarter of the population undernourished and 27 per cent of children under five malnourished (UNEP, 2007). Rainfall patterns make this country the driest and most at risk in Africa (Sassi, 2012). Indeed, precipitation is concentrated in four months only, and it is extremely variable over space, according to the ecological zones, and over time, with extreme weather events more frequent than normal.

The Sudanese agriculture is based on three farming systems, the traditional and mechanised rain-fed agriculture and the irrigated sector. According to the data provided by the General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests, the former two sectors

contribute to the production of the majority of staple foods, that is all millet and 75.93 per cent of sorghum. The Sudanese grain diet is completed by wheat, which instead is mainly grown with the irrigation system. As millet, sorghum and wheat are the major sources of food availability in the country, the paper limits climate-induced damage to these three crops. Nevertheless, rain-fed agriculture is also important for the economic access to food, as 70 per cent of the population depends on this sector for employment, income and, more generally, livelihood.

The above mentioned dimensions of the concept of food security introduced by the 1996 World Food Summit, i.e. food availability and access, are the specific focus of this paper. More precisely, the research questions of this paper are: according to the historical rainfall data, what is the likely change in millet, sorghum and wheat productivity and its probability of occurrence? Hence, what is the impact of such a change on food availability and household access to food and on the overall economy of the country? The answer is provided by integrating two methodologies: the stochastic analysis and the CGE model.

In the literature, the economic impact of climate change has been assessed by either partial equilibrium or general equilibrium approaches. The former depict only part of an overall economy. On the contrary, general equilibrium models look at the economy as a whole system, where industries have an effect on each other or the rest of the economy; thus they provide an economy-wide analysis that may capture the links between the sector affected by the shock (in our case millet, sorghum and wheat) and the others (Zhai et al., 2009).

With the CGE model, this paper takes into consideration both of them, within an economy-wide approach. This analytical perspective is lacking in the investigation developed with respect to Sub-Saharan Africa. There are examples for Asia, such as the study of van der Mensbrugghe (2010).

More precisely, the paper uses the CGE model developed at the International Food Policy Research Institute (IFPRI) by Lofgren et al. (2002). The model is based on the 2004 social accounting matrix (SAM) for Sudan (Siddig, 2011), thereby considering the country prior to the separation. What is more, the CGE model is augmented with a stochastic component in order to simulate three different rainfall scenarios, which are the result of a risk analysis approach using Monte Carlo methods. This paper does not simulate the "10 per cent shock" traditionally adopted by the empirical literature due to its easy interpretation. Instead, the stochastic method allows defining the extreme values of an interval, within which the effect of the simulated shocks has a 90 per cent probability to happen, and its mean value, if the historical trend is confirmed.

To this aim, a stochastic shock-parameter is added to the value-added function. A similar methodology has been adopted by Harris et al. (2001) with the aim of simulating the general uncertainty in agriculture and/or uncertainty caused by ENSO (El Niño/Southern Oscillation) events in Mexico. However, in comparison to that analysis, this paper improves the definition of the stochastic shocks.

Another new element introduced by this paper is that it goes far beyond the traditional economy-wide general equilibrium analysis developed for Sudan, which only assesses the impact of trade liberalisation or exchange rate policies (Elbushra et al., 2010; Siddig, 2011; Siddig and Babiker, 2011).

The analysis developed here can contribute to better inform the current debate underway in Sudan on the strategy and the actions needed to tackle climate change, consequent to the signature of the international

agreements and conventions such as the Kyoto Protocol and UNFCCC and the completion of its National Adaption Programme for Action (NAPA) (Zakieledeen, 2009).

The paper is structured as follows: section 2 introduces the methodology, articulated into the stochastic model and the CGE model; section 3 discusses achievements starting from the stochastic model, moving on to the scenarios and the related shocks simulated in the CGE model; section 4 concludes.

2. METHODOLOGY

2.1 Stochastic method

Risk analysis refers to the Monte Carlo method, a computer-based approach developed in the 1940s that uses statistical sampling techniques to obtain a probabilistic approximation to the solution of a mathematical equation model (Metropolis 1949; Hayse 2000).

It starts with the definition of the parametric model that explains the phenomena investigated and the estimation of its parameters. Then a probability distribution function is assigned to each of the input stochastic explanatory variables. The output from the model is calculated many times, randomly selecting a new value from the probability distributions for each of the input explanatory variables every time. The outputs from each run of the model are saved and a probability distribution for the output values is generated. This allows the probability of occurrence of any particular output value to be calculated. This paper makes reference to such values for the definition of the adopted scenarios.

The choice of the functional form of the parametric model, adopted to explain the effect of rainfall on yields of different crops, is based on a preliminary evaluation of outcomes, testing alternative simple (linear and log-linear) and more advanced functional forms. The paper refers to a generalised quadratic function, which results a reasonable approximation to the 'true' picture. This is defined as:

$$Q_{c,t} = \alpha RF_t + \beta RF_t^2 + \gamma T_t + \mu_t \tag{1}$$

where Q_c represents productivity of crop c ($c = millet, sorghum\ and\ wheat$) at time t. Yield is expressed in kg per feddan (1 feddan = 1.038 acres or 0.42 ha), RF is the mm of rainfall, α β and γ are the parameters to be estimated, T is the time trend and μ is the random error term.

The rainfall effect on productivity is assumed to be positive but to diminish at the margin: excessive rainfall hampers agricultural output. For this reason, the sign of the square term of rainfall is expected to be negative (Eboh et al. 2012; Teklu et al. 1991).

Turning to the impact variable, yield is preferred to the quantity produced because in Sudan the level of production is strongly dependent on the amount of land planted for the three crops taken into consideration, as shown in Figure 1, 2 and 3.

Figure 1 – Millet: Production (000 tons), yield (kg/fed) and area planted (feddan) (1954/53 – 2007/06).
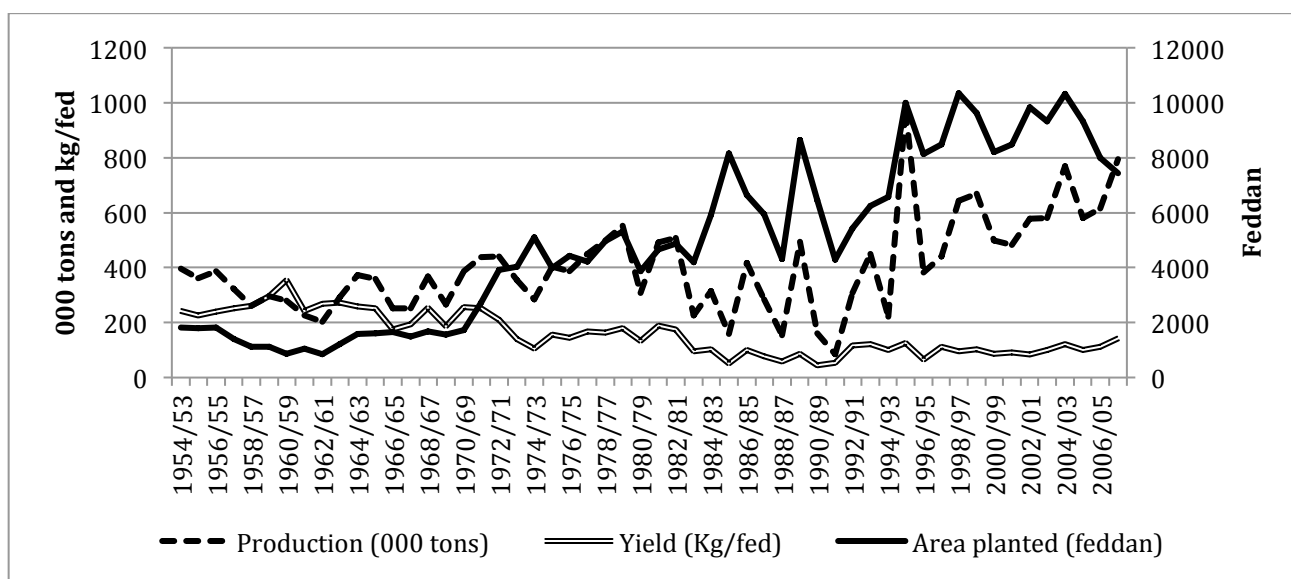
Source: authors' elaboration based on data provided by General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests

Figure 2 – Sorghum: Production (000 tons), yield (kg/fed) and area planted (feddan) (1954/53 – 2007/06).
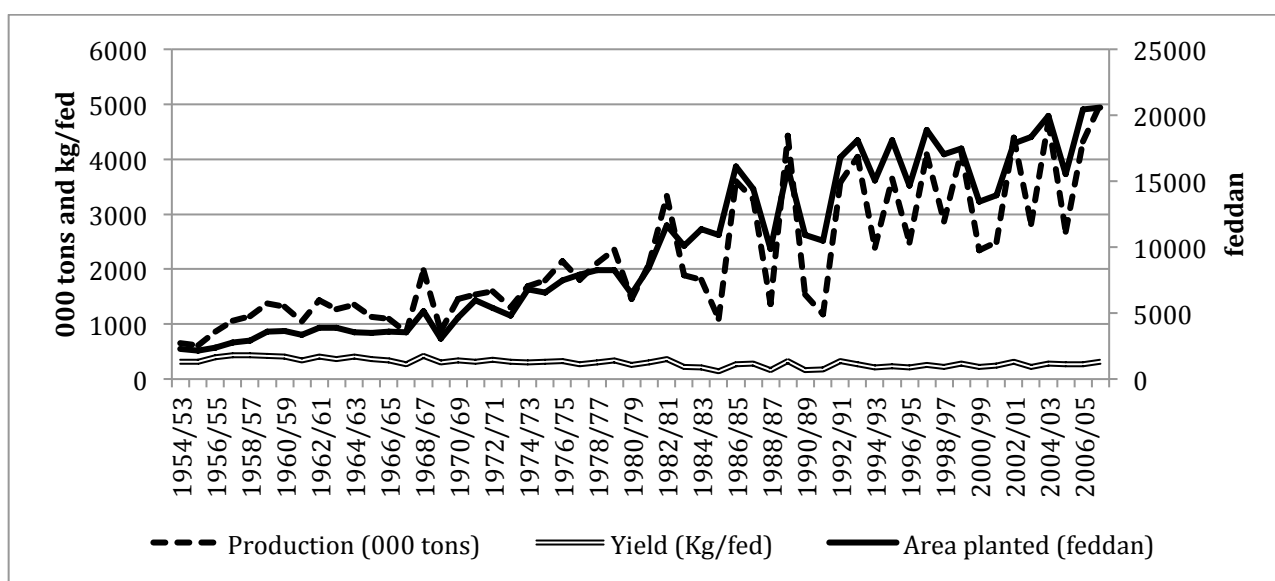
Source: authors' elaboration based on data provided by General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests

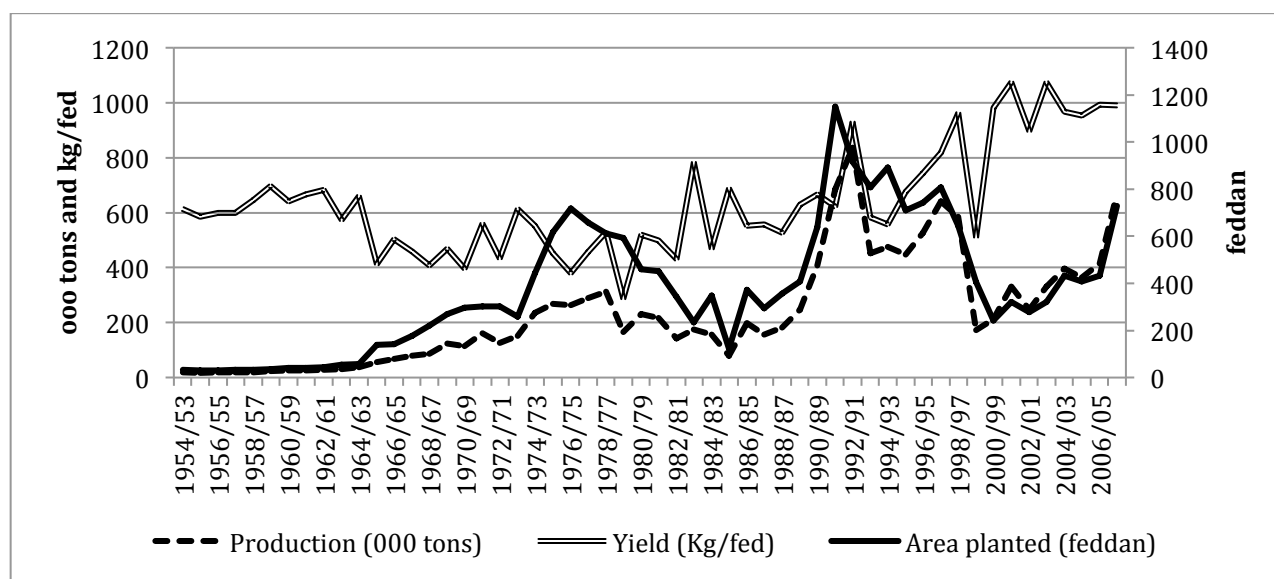Figure 3 – Wheat: Production (000 tons), yield (kg/fed) and area planted (feddan) (1954/53 – 2007/06).

Source: authors' elaboration based on data provided by General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests

Data make reference to the time period from 1954/53-2007/06. Information on yields has been provided by the General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests. Precipitation data till 1999 are those elaborated at the aggregate level for Sudan by Tim Mirchell and available at the web site http://www.cru.uea.ac.uk/cru/data/hrg/. Information from 2000 to 2007 has been provided by the Arab Organization for Agricultural Development disaggregated by meteorological station. This latter has been aggregated at the country level adopting the same methodology followed by Mirchell, that is the simple average precipitation by meteorological station.

Figure 4 shows the historical data for rainfall and its linear trend suggesting a decreasing tendency over the time period taken into consideration and wider fluctuations starting from the 1980s.

In order to characterise the stochastic model, the likely values assumed by rainfall and its square value are represented by a probability density function (PDF). For rainfall, it makes reference to the historical data of precipitation and it is defined by introducing hypothesis on the lower and upper bound. Harris et al. (2001) introduce a normal PDF for precipitation, with values included between $\pm\infty$. On the contrary, this analysis assumes the lower bound equal to zero, due to the fact that precipitation cannot have a negative value, and the upper bound limited but unknown, in order to include extreme weather events, such as floods. Furthermore, the distribution function is not selected a priori as in the above-mentioned study by Harris et al. (2001). In fact, it is chosen according to three statistics tests, which measure the compatibility of rainfall and its square value with the selected PDF: they are the Chi-squared statistic (C-S), the Kolmogorov-Simirnov statistic (K-S), Anderson-Darling statistic (A-D) (Palisade Corporation 2010).

Figure 4 – Rainfall: historical data and trend – mm (1954/53-2007/06).
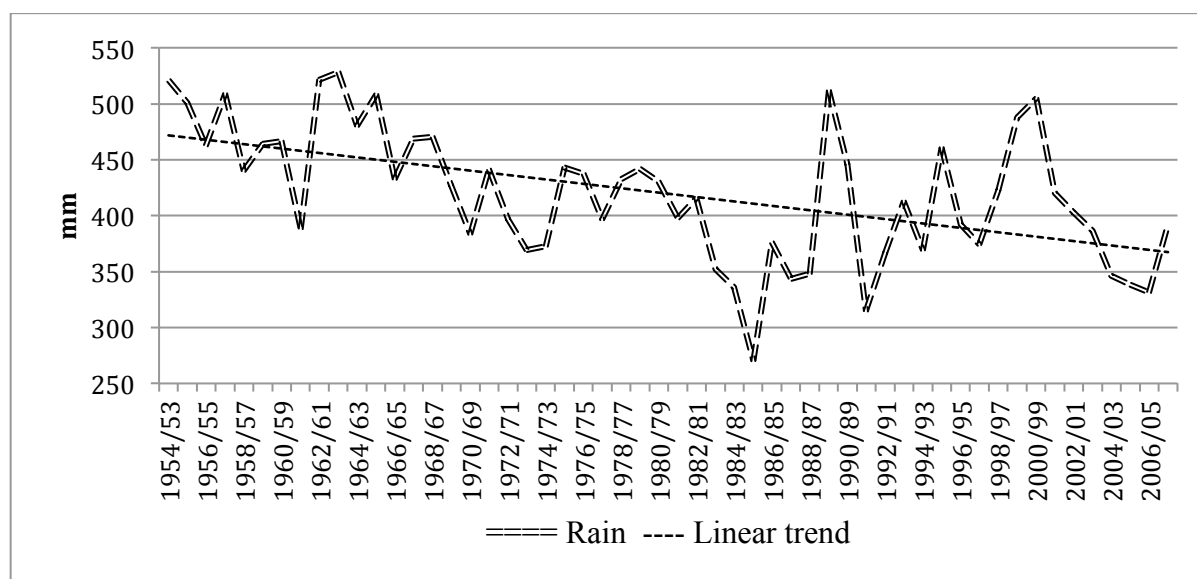
Source: authors' elaborations based on Mirchell and Arab Organization for Agricultural Development

The chosen PDF is substituted to RF, while its square value replaces RF^2. Hence, the stochastic model is estimated for each crop assuming 5,000 iterations. Finally, the output of each stochastic model is represented in the form of a cumulative ascending density function: it expresses the probability that the yield of crop c assumes a value less than or equal to some value q_c, that is $F(Q_c) = Prob(Q_c \leq q_c)$ (Risk Assessment Forum 1997). The mean, the upper and the lower delimiter values of the PDF for sorghum, millet and wheat productivity are adopted to define the three scenarios simulated with the CGE model; their change with respect to the figure in 2007/06 has represented the baseline, the best and worst scenario respectively. The upper and the lower delimiter values make reference to a 90 per cent probability for the random variable to take on a value included between them.

2.2 CGE model

The paper refers to the CGE model developed at IFPRI by Lofgren et al. (2002) and adjusted to the specific focus of the analysis and the Sudanese economic features. This is a multi-sectorial, economy-wide model, made up of linear and nonlinear equations describing the payments from each account to the others in a SAM. In particular, the analysis is based on the 2004 SAM for Sudan (Siddig, 2011). This latter is aggregated for the purpose of the study in a six-sectors-SAM that features 27 accounts (Table 1).

Table 1 – Accounts in the SAM.

Activities		Food Industry commodity	CFIN	Other domestic institutions	
Wheat activity	AWHE	Industry commodity	CIND	Enterprises	ENTR
Other cereals activity	ACER	Services commodity	CSER	Government	GOV
Other Agriculture Activity	AOAG	Factors		Taxes and other accounts	
Food Industry activity	AFIN	Labour	LABO	Direct taxes	YTAX
Industry activity	AIND	Land	LAND	Indirect taxes	ATAX
Services activity	ASER	Capital	CAPI	Import tariffs	TAR
Commodities		Households		Activity subsidy	ASUB
Wheat commodity	CWHE	High-income households	HHHI	Saving and investment	S-I
Other cereals commodity	CCER	Middle-income households	HHMI	Rest of the world	ROW
Other Agriculture commodity	COAG	Low-income households	HHLI	Total	

In the matrix, cereal accounts are those interested by the simulated shocks. Due to the lack of data, millet and sorghum are taken as aggregate in the account "other cereals". Among institutions, households have a specific importance in the analysis. In the SAM they are disaggregated into three categories according to their level of income.

The structure of the CGE model, illustrated in Figure 5, fits the SAM and identifies activities' production process, that is the supply side of the model, and the flow of marketed commodities, which is the demand side instead. The model allows analysing two of the basic pillars of the food security concept provided by the 1996 World Food Summit, i.e. food availability and access to food (Sassi, 2006). The former is determined by the disposable amount of composite commodities that, in combination with market prices and household income, brings about the economic access to food, which is represented by consumption. These two dimensions are referred to at the household level of analysis.

Figure 5 – Structure of the CGE model with food security pillars of food availability and access to food.
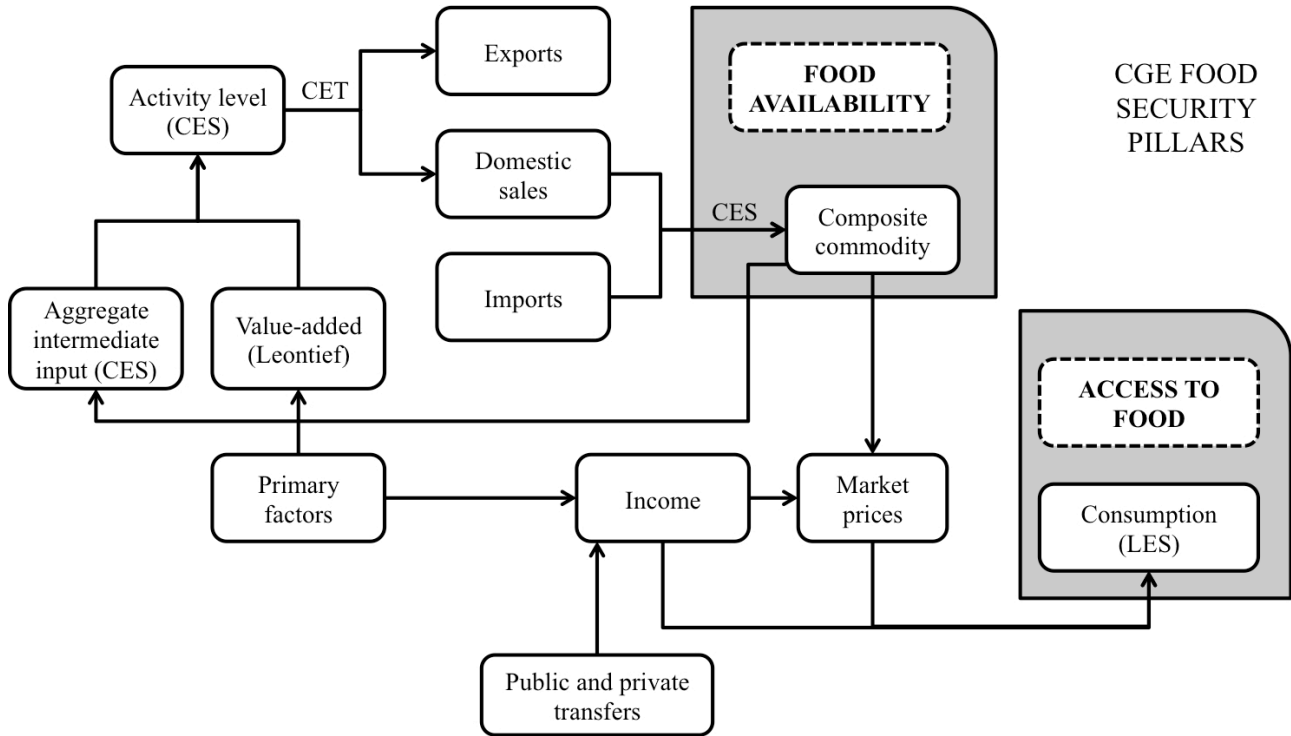
Source: authors' elaboration
Note: CES is Constant Elasticity of Substitution function; CET is Constant Elasticity of Transformation function; LES is Linear Expenditure System.

Within this framework, the stochastic component represented by rainfall affects the value-added function. For this reason, following Harris et al. (2001) and Karaky (2002), the value-added equation provided by the standard CGE model is modified. Originally, this function is shaped as:

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot QF_{f\,a}^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \qquad (2)$$

where QVA_a is the quantity of aggregate value-added; α_a^{va} is the efficiency parameter and $\delta_{f\,a}^{va}$ is the share parameter for factor f in activity a; ρ_a^a is the CES value-added function exponent (that is a transformation of the elasticity of substitution); $QF_{f\,a}$ is the quantity demanded of factor f from activity a. The modified version of this equation includes a new parameter, namely rf_a^S. That is:

$$QVA_a = [rf_a^S \cdot \alpha_a^{va}] \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot QF_{f\,a}^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \qquad (3)$$

where rf_a^S is the parameter representing the shock to cereal producers ($a = wheat, other\ cereals$) in the three scenarios ($s = baseline, best\ scenario, worst\ scenario$). As in Harris et al. (2001), the shocks are

Hicks-neutral technological shocks, meaning that the proportion of inputs for each output remains the same. In equation 3, rf_a^S is such that $0 < rf_a^S < 1$. As a matter of fact, rf_a^S is defined as:

$$rf_a^S = 1 + rain_a^S \qquad (4)$$

where $rain_a^S$ equals the results of the risk analysis.

2.2.1 Model closure

A final aspect taken into consideration for the definition of the CGE model is its closure. The macroeconomic consistency of the model is achieved imposing a number of constraints. These refer to the savings-investment balance, the government balance and the current account balance. Furthermore, since the way macroeconomic variables adjust in the modelled economy is determined by the choice of the constraints (Thurlow et al., 2002), these latters have to be set up looking at the way macroeconomic causalities work in the Sudanese economy.

In particular, an investment-driven closure is used, with savings being the flexible variable (Elbushra et al, 2010; Siddig, K. et al., 2011). Such a constraint implies savings to adjust as investment varies. Moreover, in the government balance, government savings is the endogenous variable, whereas all tax rates are exogenous (Hassan et al., 1996; Elbushra et al, 2010; Siddig, K. et al., 2011). Finally, in the current account balance, foreign savings is the flexible variable, whilst the real exchange rate is fixed.

Such a set of constraints seems to fit the Sudanese context for different reasons.

As the closure is investment-driven, the level of investment depends on entrepreneurs' long-term expectations and the role of assuring that investment is fully financed falls on savings. Therefore, in order to enable private savings to follow investment variations, the base-year savings rates of domestic non-government institutions adjust by the same number of percentage points. Nevertheless, in Sudan, the share of government savings in total domestic savings is equal to 68%, thus meaning that government savings plays the most important role in assuring that investment is fully financed (a similar criterion has been adopted by Lofgren et al. (2001) for setting fixed investment quantities in a CGE model for Malawi). Using data from the base simulation in our model, we have calculated this share as:

$$\frac{GSAV}{\sum_{i \in INSDNG} MPS_i \cdot (1 - \overline{TINS_i}) \cdot YI_i + GSAV} \qquad (5)$$

where $GSAV$ is government savings, MPS_i is the marginal propensity to save of domestic nongovernment institutions ($INSDNG$), $TINS_i$ is the direct tax rate for such institutions and YI_i is their income. Hence, $\sum_{i \in INSDNG} MPS_i \cdot (1 - \overline{TINS_i}) \cdot YI_i$ is private savings and, together with government savings, it combines to

bring about total domestic savings. This is derived from equation 6, which identifies the savings-investment balance in the model as:

$$\sum_{i \in INSDNG} MPS_i \cdot (1 - \overline{TINS_i}) \cdot YI_i + GSAV + \overline{EXR} \cdot FSAV = \sum_{c \in C} PQ_c \cdot \overline{QINV_c} + \sum_{c \in C} PQ_c \cdot qdst_c \quad (6)$$

The left-hand side of this equation identifies total savings, whereas the right-hand side describes total investment. In addition to the already defined variables, EXR is the exchange rate and $FSAV$ is foreign savings (i.e. the current account deficit). On the right-hand side, $QINV_c$ is the quantity of investment demand for commodity c, PQ_c is the composite commodity price and $qdst_c$ is the quantity of stock change.

Moreover, as Taylor et al. (2006) point out, the idea behind flexible government savings is that governments across the globe use automatic stabilisers and public works programmes to counter negative effects of economic downturns, thus meaning the deficit (and not tax revenue) is endogenous. Finally, concerning the current account balance, Sudan has a managed exchange rate regime (Collier et al., 1989; Hassan et al., 1996; Elbushra et al, 2010; Siddig, K. et al., 2011) thus leaving us no choice but to make foreign savings the clearing variable.

3. RESULTS

3.1 The parametric model

Results achieved by estimating equation 1 for millet and sorghum, through an Ordinary Last Square (OLS) method, are illustrated in the following equations:

$$Q_{millet,t} = \underset{(0.0000)}{0.9665} * RF_t - \underset{(0.0083)}{0.0008} * RF_t^2 - \underset{(0.0000)}{3.4435} * T_t + \mu_t$$

$$R^2 = 0.9484; \ F = 312.3 \ (0) \tag{7}$$
(…) p-value

$$Q_{sorghum,t} = \underset{(0.0000)}{1.4576} * RF_t - \underset{(0.0006)}{0.0014} * RF_t^2 - \underset{(0.0000)}{2.4659} * T_t + \mu_t$$

$$R^2 = 0.9752; \ F = 668.5 \ (0) \tag{8}$$
(…) p-value

For wheat, the trend variable is not statistically significant. In risk analysis the definition of the parametric model represents an important phase because the output of the stochastic model is sensitive to its structure. The literature suggests to consider only the model input parameters that contribute the most to explain the phenomena investigated, excluding those unimportant (Palisade Corporation 2010; Risk Assessment Forum 1997). For this reason, the stochastic model for wheat refers to the following parametric model:

$$Q_{wheat,t} = \underset{(0.0000)}{3.7784} * RF_t - \underset{(0.0000)}{0.0053} * RF_t^2 + \mu_t$$

$R^2 = 0.9176;\ F = 289.6\ (0)$ (9)

$(\ldots)$ p-value

In the three equations, the estimated parameters are statistically significant and show the expected sign. Wheat productivity is the most sensitive to rainfall, followed by that of sorghum and millet. Millet is the most inherently drought-tolerant of all the major staples representing a key cereal grain crop in the dry-lands. In general, millet fits in the same areas of adaptation as sorghum, except that it is somewhat more drought tolerant (http://www.cgiar.org/impact/global/des_fact2.html).

The sign of the estimated parameters suggests that precipitation affects the productivity of all the three crops but at a decreasing rate. Finally, the trend variable has a statistically significant negative impact on sorghum and millet productivity.

3.2 The stochastic model

The stochastic model derives from the above equations, substituting a probability density function to the explanatory variables, that is mm of precipitation and its square value. A Riskbetageneral function fits the historical data of precipitation: all the statistics tests have the lowest value for this distribution function (Table 2).

Table 2 – Rainfall (RF): Specification of the probability distribution functions and statistics test.

Function	C-S	K-S	A-D
RiskBetaGeneral(15.401;7,4421;0;622.57)	3.6667	0.3399	0.0807
RiskTriang(0;528.3;528.3)	28.6667	27.2467	0.3561
RiskUniform(0;538.27)	76.6667	+infinity	0.5784

Note: (…) are the arguments of the function

The parametric models are rewritten, substituting to *RF* the function RiskBetaGeneral(15.401;7,4421;0;622.57), to RF^2 its square value, and to *T* the number 55 that is the number of observations plus one.

The output from the stochastic model for each crop is represented in terms of a probability distribution function with the indication of the mean value and the delimiters corresponding to a 90 per cent probability. This information is summarised in Table 3.

Table 3 – Output from the stochastic models.

	Sorghum	Wheat	Millet
Mean value	224.47	633.36	72.53
Upper delimiter	243.50	673.10	95.40
Lower delimiter	184.60	538.60	33.40

The scenarios adopted to define the shocks simulated in the CGE model are delineated on the basis of these values calculating the change between each of them and the 2007/06 corresponding figure. The baseline is defined with the mean value, the best scenario with the upper delimiter value and the worst scenario with the lower delimiter value. As previously underlined, the SAM on which the CGE model is based, considers millet and sorghum together in the account "other cereals". Thus, the percentage change for the quantity produced by this aggregate category is obtained as the weighted average of the sorghum and millet values, using the average harvested area of the last ten years as a weight. Table 4 illustrates the scenarios adopted in the analysis, as well as the simulated shocks that are computed on the basis of equation 4.

Table 4 – Scenarios and shocks.

	Scenarios		Shocks	
	Wheat	Other cereals	Wheat	Other cereals
Baseline (mean value)	-0.3600	-0.3575	0,6399	0,6424
Best (upper delimiter)	-0.3198	-0.2667	0,6801	0,7332
Worst lower delimiter)	-0.4557	-0.5287	0,5442	0,4712

Looking at the results from the simulations in the CGE model, the best and the worst scenario can be interpreted as the extreme values of an interval within which there is a 90 per cent probability for the impact to happen.

3.3 CGE food security pillars

3.3.1 Food availability

Under the effect of the three shocks simulated in this paper, food security in Sudan is expected to deteriorate significantly.

Figure 6 underlines the negative impact on food availability in terms of quantities of commodities available on the domestic market. The change is stronger for the commodities directly affected by the shocks, i.e. wheat and other cereals. Indeed, for wheat there is a 90 per cent probability for the reduction to be included between -5.32 per cent and -11.71 per cent, while for other cereals the intensity of the shock is expected to be within -16.87 per cent and 34.53 per cent.

In this context, the quantities imported (Figure 7 – Panel b) do not counterbalance the reduction in domestic supply (Figure 7 – Panel a).

Figure 6 – Change in quantity of composite commodities by commodity and shock.
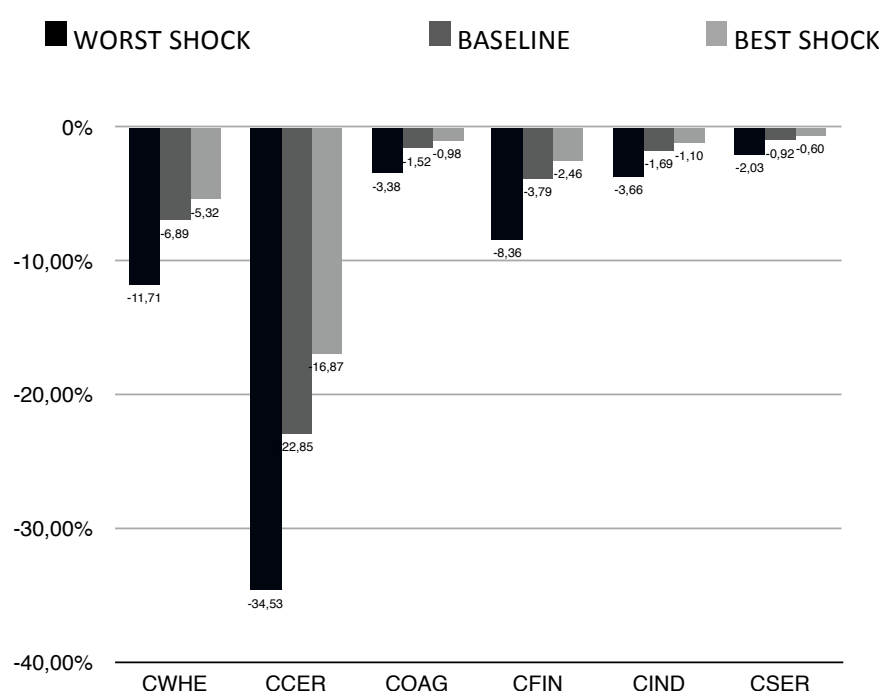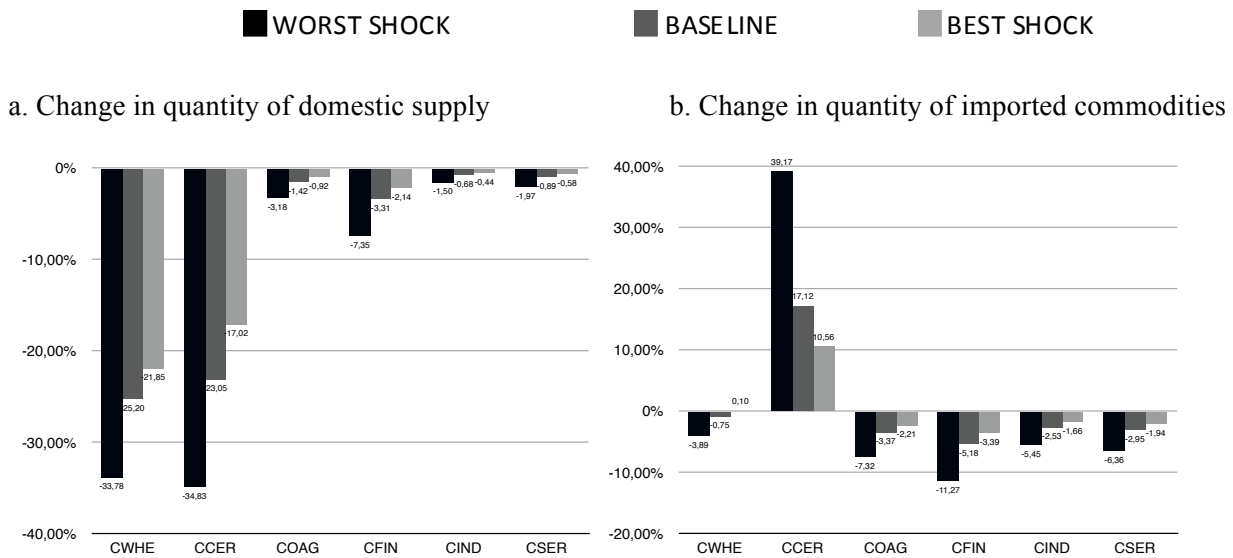
Figure 7 – Change in quantity of domestic supply and of imported commodities by commodity and shock.

a. Change in quantity of domestic supply

b. Change in quantity of imported commodities

As far as imported quantities are concerned, it should be noticed that they increase only for sorghum and millet, due to the significant demand price hike for domestic production (Figure 8) that, combined with the elasticity of substitution with domestic demand, generates an incentive to buy on the international market. This is formally explained by the equation of the import-domestic demand ratio, which is specified in the model as:

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q}\right)^{\frac{1}{1+\rho_c^q}}$$

(10)

where QM_c is the quantity of imports of commodity c, QD_c is the quantity sold domestically of domestic output, PDD_c is the demand price for commodity produced and sold domestically, PM_c is the import price (in domestic currency). In addition, δ_c^q is the Armington function share parameter, whereas ρ_c^q is the Armington function exponent.

Given the fixed import price in our simulations, a rise in PDD_c causes imported quantities to grow. The responsiveness of such a change, following a modification of PDD_c/PM_c, depends on the elasticity of substitution between imports and domestic supply.

Also the domestic price of wheat increases as a consequence of the shocks, but in this case the intensity of the change is not marked enough to incentivise a shift from domestic supply towards imports.

Figure 8 – Change in domestic demand price by commodity and shock.
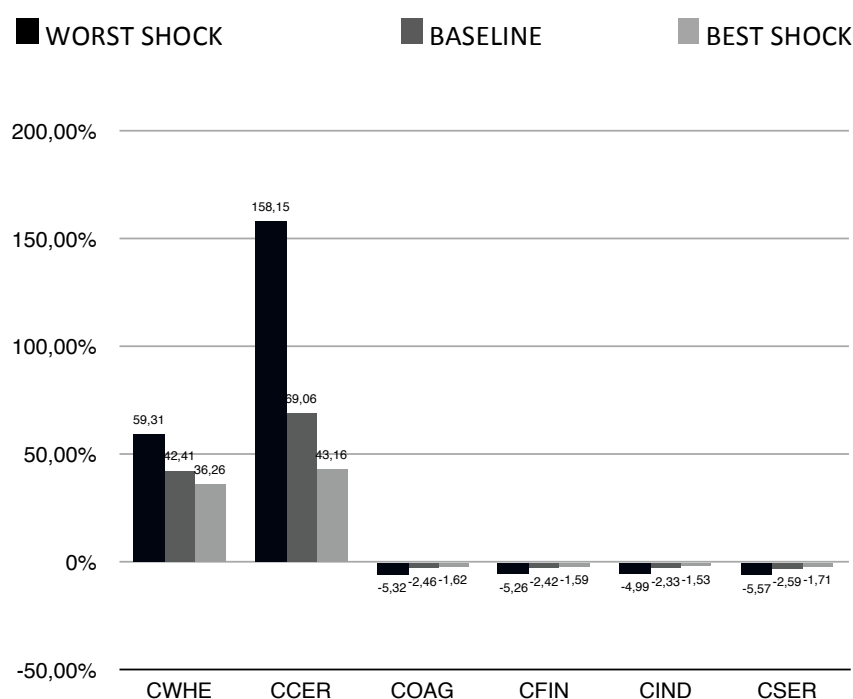
3.3.2 Access to food

On the domestic market the reduction in food availability combines with an increase in prices of wheat and other cereals (Figure 9). Particularly this latter is dramatically affected by the shocks with an expected change included between 156.66 per cent and 42.83 per cent.

This situation, in a context of 90 per cent probability of a drop in household income that for all the categories is on average between 2 and 6 per cent, explains the result of the simulations on access to food illustrated in Figure 10: all the household categories report a reduction in quantities consumed for all commodities.

Figure 9 – Change in price of composite commodities by commodity and shock.

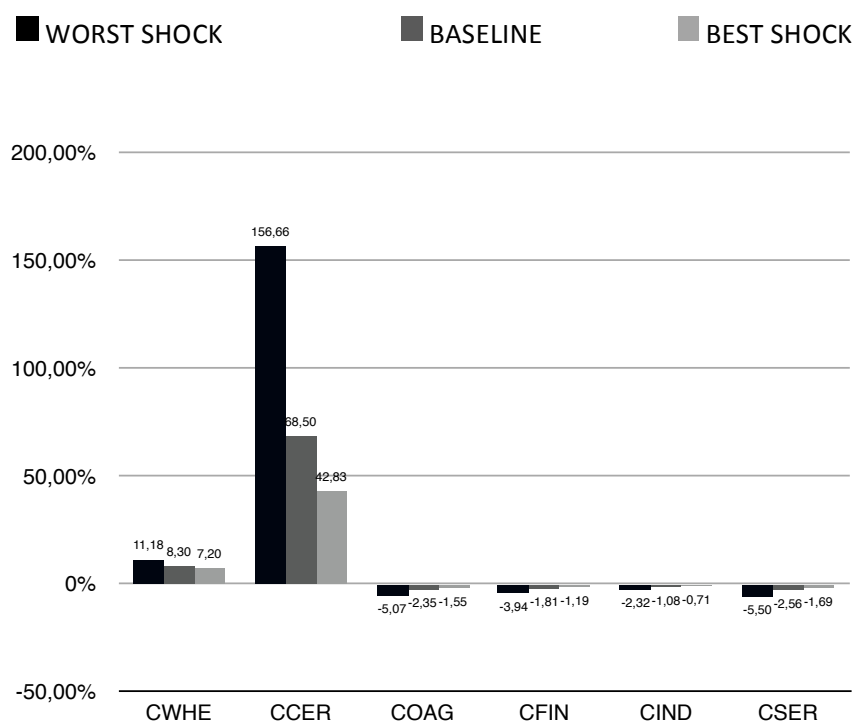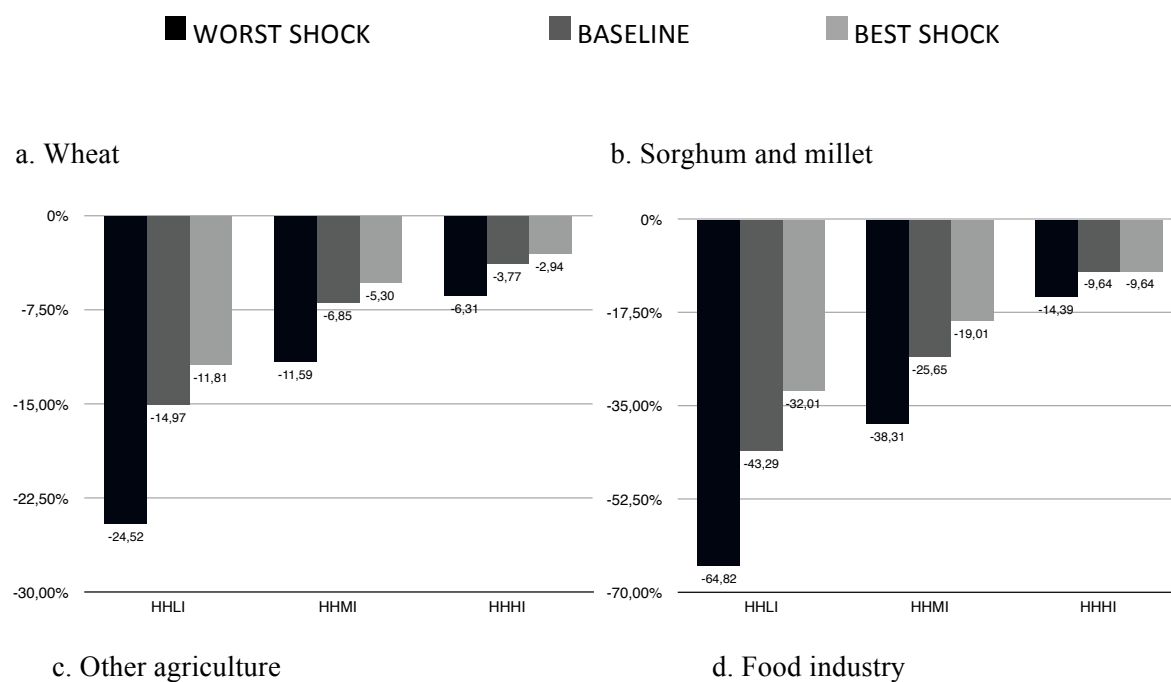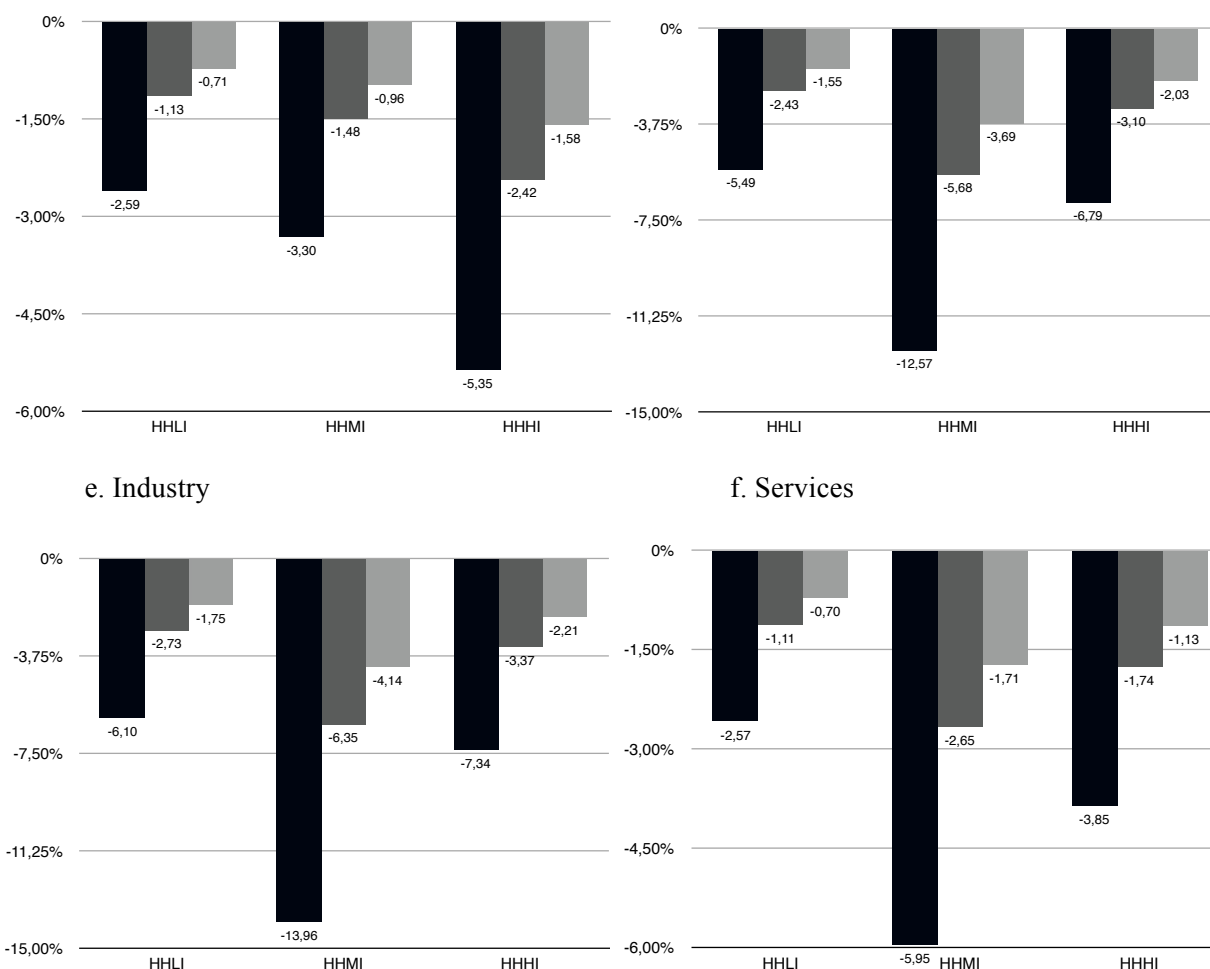
Figure 10 – Change in quantity of consumed commodities by households and shock.

a. Wheat   b. Sorghum and millet

c. Other agriculture   d. Food industry

Top left chart (HHLI, HHMI, HHHI):
- HHLI: -2,59; -1,13; -0,71
- HHMI: -3,30; -1,48; -0,96
- HHHI: -5,35; -2,42; -1,58
(Axis: 0%, -1,50%, -3,00%, -4,50%, -6,00%)

Top right chart (HHLI, HHMI, HHHI):
- HHLI: -5,49; -2,43; -1,55
- HHMI: -12,57; -5,68; -3,69
- HHHI: -6,79; -3,10; -2,03
(Axis: 0%, -3,75%, -7,50%, -11,25%, -15,00%)

e. Industry

- HHLI: -6,10; -2,73; -1,75
- HHMI: -13,96; -6,35; -4,14
- HHHI: -7,34; -3,37; -2,21
(Axis: 0%, -3,75%, -7,50%, -11,25%, -15,00%)

f. Services

- HHLI: -2,57; -1,11; -0,70
- HHMI: -5,95; -2,65; -1,71
- HHHI: -3,85; -1,74; -1,13
(Axis: 0%, -1,50%, -3,00%, -4,50%, -6,00%)

Other cereals demand shows the highest expected reduction with the possibility for the low-income households to reduce by half their consumption. In general terms, this household category is the most affected by the shocks simulated on the side of wheat and other cereal demand, followed by middle and high-income households.

However, the direction of the shocks intensity is opposite for other agricultural products: most of the burden of the consequences of the three shocks is on high-income households. Instead, concerning demand for other crops, the greatest fall in quantity consumed is for middle-income households.

A noteworthy issue regards wheat and other cereals. As a matter of fact, the impact on food security of low-income households is even more severe considering that these two commodities are staple food and that, for this household category, other cereals represents more than 50 per cent of their total demand for cereals (figure 11).

Figure 11 – Share of cereals consumption by household.
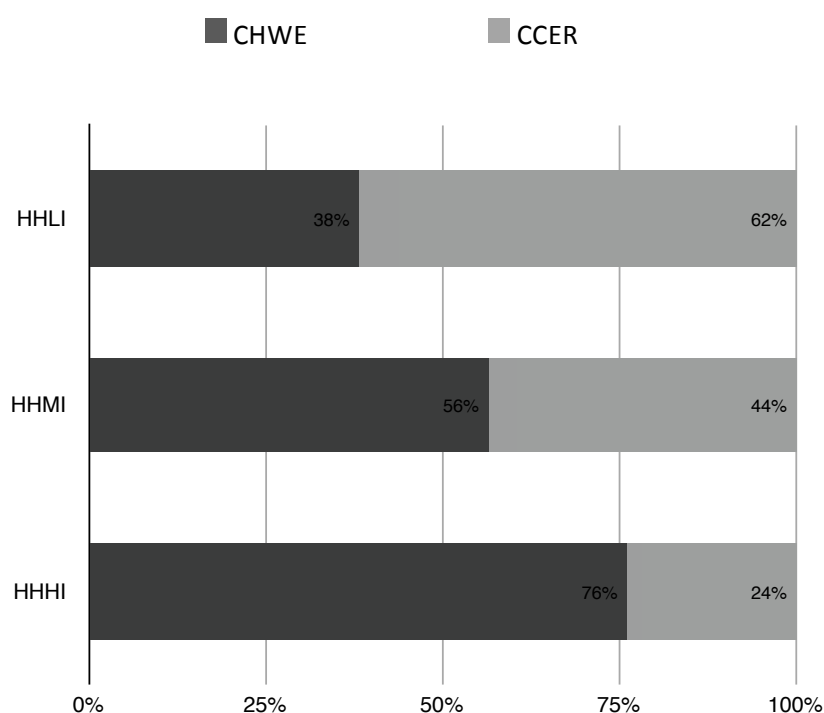
3.4 Food consumption and aggregate national accounts

The analysis of the production accounts has underlined a typical feature of the Sudanese economy: due to the low level of development of the country, backward and forward linkages are weak. This highlights that the simulated shocks primarily affect the wheat and other cereals accounts in a very significant way. However, the shocks simulated in this paper have an impact also on the macroeconomic accounts, as illustrated in Table 5.

Table 5 – GDP and the aggregate national accounts in nominal and real terms.

NOMINAL	WORST SHOCK	BASELINE	BEST SHOCK
Private consumption	-8.13	-3.74	-2.44
Investment	-4.51	-2.09	-1.38
Government consumption	-5.49	-2.56	-1.68
Exports	6.41	2.88	1.88
Imports	-5.82	-2.59	-1.64
GDP (at market prices)	-4.97	-2.32	-1.53

REAL	WORST SHOCK	BASELINE	BEST SHOCK
Private consumption	-6.47	-3.23	-2.20
Investment*	-	-	-
Government consumption*	-	-	-
Exports	6.41	2.88	1.88
Imports	-5.82	-2.59	-1.64
GDP (at market prices)	-2.28	-1.26	-0.89

*Real investment, as well as real government consumption, does not vary by closure assumption.

A noteworthy aspect is the inflationary pressure caused by all the shocks. This is the particular result of a "cereal inflation", as illustrated in Figure 9.

Moreover, the change in the GDP suggests a negative impact on the economic performance of the country that has a 90% probability of being included, in real terms, between -0.89 per cent and -2.28 per cent. This reduction is the result of a contraction in private consumption, while the balance of trade improves.

In nominal terms, the inflationary pressure aggravates the contraction in private consumption, while the emerged reduction in government consumption and fixed capital formation is related to the reduction in prices.

Regarding the balance of trade, two aspects should be pointed out. First, as suggested by Figure 2.b and 12, its improvement is related to the different directions of the shocks on the accounts that are not directly affected by them.

Figure 12 – Change in quantity of exports* by commodity and shock.
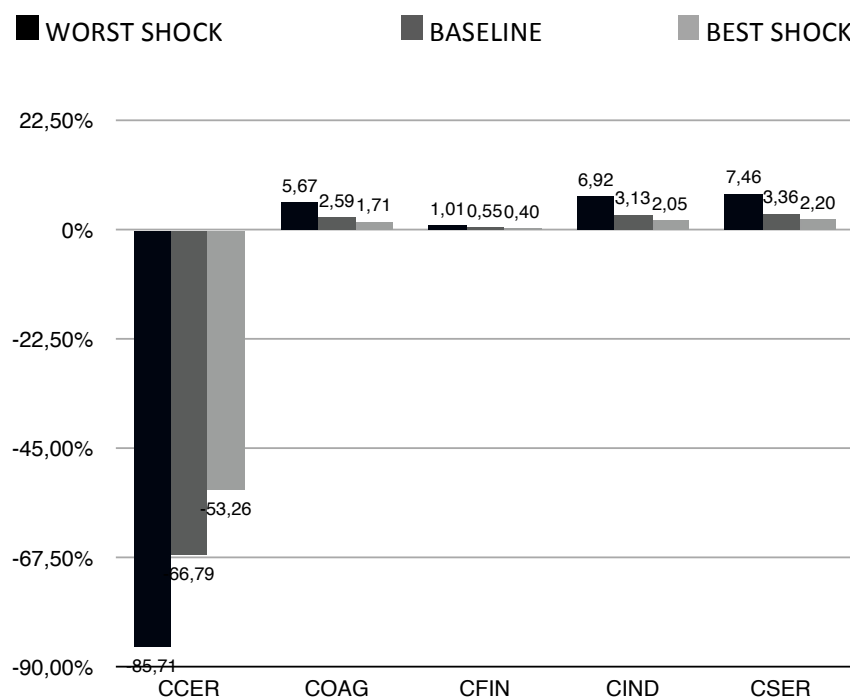
*Wheat is not included because it is not exported

The "export incentive" provided to non-cereal activities is related to the reduction in domestic demand prices for these accounts (Figure 8) in a context of fixed export prices, in combination with the elasticity of substitution with domestic demand. This is captured by the export-domestic demand ration, which in the model is written as:

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t-1}} \tag{11}$$

where QE_c is the quantity of exports, QD_c is the quantity sold domestically of domestic output, δ_c^t is the CET function share parameter and ρ_c^t is the CET function exponent.

Secondly, the improvement in the balance of trade is also explained by the fact that cereals represent only 0.10 per cent of total exports and 9.34 per cent of total imports.

Another important negative aspect that has to be highlighted is the reduction in nominal government consumption that represents an important component of the GDP and, thus, of the Sudanese economic growth and development.

4. CONCLUSIONS

By integrating a stochastic and a CGE model, this paper has investigated the consequences of different rainfall scenarios on food security in Sudan with a specific focus on food availability and household access to food.

From 1953/54 to 2006/07, precipitation in Sudan has reduced and the estimated parametric model has confirmed its direct correlation with the productivity of sorghum, millet and wheat and the decreasing rate of its intensity over time as suggested for the 1980s by Teklu et al. (1991). If the historical rainfall trend is confirmed, the stochastic model has predicted a further reduction of the yield for the three selected crops, confirming the expectations provided by the literature (UNEP, 2007; NAPA, 2007). On the basis of these predictions, the CGE model has suggested a dramatic deterioration of both food availability and access to food as a consequence of climate change; this is in line with the achievement of the World Food Programme (2012) according to which below-average rainfall and delayed rains have a serious impact on food security.

In the model, the decline in food availability is due to a marked reduction in the quantity of cereal commodities available on the domestic market. This is consistent with the literature arguing that the most direct impact of climate change on food security is through availability due to changes in crop productivity (Thompson, 2010). In the Sudanese case this situation is aggravated by a reduction in cereals import incentives.

The worsening in access to food, instead, arises from the combination of the expected drop in household income and the major cereal inflationary pressure. As a consequence, all household categories are affected by the climatic shocks, with the biggest impact on the poorest households. This was an expected result taking into consideration that the poorest spend more than 80 per cent of their total budget on food and that half of their total demand is for cereals (SIFSIA, 2012).

The CGE model has also made possible to identify the main macroeconomic causalities in the Sudanese economy, following the impact of rainfall shocks on food security. In this respect, the paper has first allowed addressing the open question about the possible effects of climate change on economic growth rates (Tol, 2010). The predicted contraction in private consumption under the simulated shocks is the main responsible for the expected negative economic performance of the country. This paper has suggested a 90 per cent probability for the GDP to drop between 0.89 and 2.28 per cent; the result is in line with the study by Dell et al. (2008) who argue that climate change causes a contraction of the economy of poor countries between 0.6 and 2.9 per cent.

In this context a question arises: are policies for climate change alone able to reduce the impact of less rainfall on food security in Sudan?

The literature is focused on different levels of analysis. A part of it emphasises the role of climate change policies, while another deems development interventions as viable alternatives to them, underlining the fact that they may have negative and perverse effects on economic development (Tol, 2010). Other authors study

alternative solutions to climate policies, taking into account the possibility to act on non-climatic factors (Shcelling, 2000) or to introduce adaptation and coping strategies (Huq and Ayers, 2009).

This paper does not advocate a specific policy intervention being better than others, nor it acknowledges that one area needs to be prioritised. Instead, this work clearly stresses the need to evaluate a different possible policy perspective: climate change, poverty and food insecurity are strongly interlinked, thereby suggesting a coordination of policies in these three targeted areas. In the policy-making process, it should be opened a dialogue among these three levels of intervention, with a sound integration of the climate change policy within those aimed at promoting development and food security.

ACKNOWLEDGMENTS

REFERENCES

- Adger, W. N. (2006). Vulnerability. *Global environmental change,* 16: 268-281.

- Arndt, C. and Tarp, F. (2000). Agricultural technology, risk and gender: A CGE analysis of Mozambique. *World Development* 28(7): 1307-1326.

- Collier, P. and Joshi, V. (1989). Exchange rate policies in developing countries. *Oxford review of economic policy* 5(3): 94-113.

- Dell, M., Jones, B. F. and Olken B. A. (2008). Climate change and economic growth: Evidence from the last half century. NBER Working Paper, 14132. Cambridge, MA: National Bureau of Economic Research.

- Eboh, E., Oduh, M, Ujah, O (2012). Drivers and Sustainability of Agricultural Growth In Nigeria, AIAE Research Paper 8. http://www.aiaenigeria.org/Publications/Researchpaper8.pdf

- Elbushra, A. A., Elsheikh, O. E. and Salih, A. A. A. (2010). Impact of exchange rate reforms on Sudan's economy: Applied general equilibrium analysis. *African Journal of Agricultural Research* 5(6): 442-448.

- Harris, R. L. and Robinson, S. (2001). Economy-wide effects of El Niño/Southern Oscillation (ENSO) in Mexico and the role of improved forecasting and technological change. TDM Discussion Papers 83, International Food Policy Research Institute (IFPRI). Washington DC: IFPRI.

- Hassan, M. R. and Hallam, A. (1996). Macro-economic linkages to agriculture: A general equilibrium model for Sudan. *Journal of Agricultural Economics* 47(1): 66-88.

Hayse, J.W. (2000). Using Monte Carlo Analysis in Ecological Risk Assessments. http://web.ead.anl.gov/ecorisk/issue/pdf/montecarlo.pdf

- Huho, J. M. (2011). Rain-fed agriculture and climate change: An analysis of the most appropriate planting dates in central division of Laikipia district, Kenya. *International Journal of Current Research*, 3,4 :172-182.

- Huq, S. and Ayers, J. (2007). Critical list: The 100 nations most vulnerable to climate change. *Sustainable development opinion*. London: International Institute for Environment and Development.

- IPCC (2007). Summary for policy-makers in M. L. Parry et al. (eds). Climate change 2007: Impact, adoption and vulnerability. Contributions of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press.

- Ito, T., Kojima, A., Mckenzie, C. and Urata, S. (2010). The environment and climate change: Editor's overview. *Asian Economic Policy Review*, 5: 1-18.

- Karaky, R. (2002). Climate variability and Agricultural policy in Morocco. PhD Thesis. West Lafayette: Purdue University, Department of Agricultural Economics.

- Lofgren, H., Chulu, O., Sichinga, O., Simotwe, F., Tchale, H., Tseka, R. and Wobst, P. (2001). External shocks and domestic poverty alleviation: Simulations with a CGE model of Malawi. TDM Discussion Papers 71, International Food Policy Research Institute (IFPRI). Washington DC: IFPRI.

- Lofgren, H., Harris, R. L. and Robinson, S. (2002). A Standard Computable General Equilibrium (CGE) Model in GAMS. Microcomputers in Policy Research 5, International Food Policy Research Institute (IFPRI). Washington DC: IFPRI.

- Metropolis, N. (1949). The Monte Carlo Method. *Journal of the American Statistical Association*, 44: 335-341.

- Palisade Corporation (2010). Guide to Using @Risk. Ithaca: Palisade Corporation.

- Ministry of Environment and Physical Development of the Republic of the Sudan (2007). National Adaptation Programme of Action (NAPA). http://unfccc.int/resource/docs/napa/sdn01.pdf

- Risk Assessment Forum (1997). Guiding Principles for Monte Carlo Analysis, EPA (630/-97/001, March). http://www.epa.gov/ncea/pdfs/montcarl.pdf

- Sassi M. (2006), *An Introduction to Food Security Issues and Short Term Responses*. Roma: Aracne.

- Sassi, M. (2012). Food prices and climate change in Sudan: A stochastic approach. Paper presented at the Seventy-third International Atlantic Economic Conference. Istanbul: 28-31 March 2012.

- Shcelling, T. C. (2000). Intergenerational and International Discounting. *Risk Analysis*, 20: 833-837.

- Siddig, K. and Babiker, B. (2011). Agricultural efficiency gains and trade liberalization in Sudan. Agricultural Economics Working Paper Series 1. Karthoum: University of Karthoum, Department of Agricultural Economics.

- Siddig, K. (2011). The controversy of exchange rate devaluation in Sudan: An economy-wide general equilibrium assessment. Agricultural Economics Working Paper Series 2. Karthoum: University of Karthoum, Department of Agricultural Economics.

- SIFSIA (2012). Sudan monthly market update, 51. Rome: Food and Agriculture Organisation (FAO) of the United Nations.

http://www.fao.org/fileadmin/user_upload/sifsia/docs/Sudan%20Monthly%20Market%20Update%20March%202012.pdf

- Smit, B. and Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global environmental change,* 16: 282-292.

- Taylor, L. and von Armin, R. (2006). Modelling the Impact of Trade Liberalisation – A Critique of Computable General Equilibrium Models. A report prepared for Oxfam International. http://oxfamilibrary.openrepository.com/oxfam/bitstream/10546/112547/1/rr-modelling-impact-trade-liberalisation-010707-en.pdf

- Teklu, T., von Braun, J. and Zaki, E. (1991). Drought and Famine Relationship in Sudan: Policy Implications. Research Report 88, International Food Policy Research Institute (IFPRI). Washington DC: IFPRI.

- Thompson, H. E., Berrang-Ford, L. and Ford, J. D. (2010). Climate change and food security in Sub-Saharna Africa: A systematic literature review. *Sustainability*, 2: 2719-2733.

- Thurlow, J. and van Seventer, D. E. (2002). A Standard Computable General Equilibrium Model for South Africa. TDM Discussion Papers 100, International Food Policy Research Institute (IFPRI). Washington DC: IFPRI.

- Tol, R. S. J. (2010). The economic impact of climate change. *Perspektiven der Wirtschaftpolitik,* 11(s1): 13-37.

- Torres, R. (2008). Notes, debates and communications. The social impact of policies to address climate change: A review of the issues. *International Labour Review*, 147 (2-3): 275-279.

- UNEP (2007). Sudan: Post-conflict environmental assessment. Nairobi: United Nations Environment Programme (UNEP). http://postconflict.unep.ch/publications/UNEP_Sudan_synthesis_E.pdf

- van der Mensbrugghe, D. (2010). Climate change policy options for Asian economies: Findings from an integrated assessment model. *Asian Economic Policy Review*, 5(1): 63-83.

- Wani, S. P., Sreedevi, T. K., Rockstrom, J. and Ramakrishna, Y. S. (2009). Rainfed agriculture: past trends and future prospects. In Wani, S. P., Rockstrom, J. and Oweis, T. (eds) Rainfed agriculture: Unlocking the potential. CAB International, London: 1-36.

- WFP (2012). Global Update – Food Security Monitoring, 6. Rome: World Food Programme (WFP). http://documents.wfp.org/stellent/groups/public/documents/ena/wfp245717.pdf http://documents.wfp.org/stellent/groups/public/documents/ena/wfp244527.pdf

- Zakieledeen, S. A. (2009). Adaptation to climate change: A vulnerability assessment for Sudan. Gatekeeper Series 142, International Institute for Environment and Development (IIED). London: IIED.

- Zhai, F., Lin, T. and Byambadorj, E. (2009). A general equilibrium analysis of the impact of climate change on agriculture in the People's Republic of China. *Asian Development Review*, 26(1): 206-225.