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Sudan Agricultural Markets Performance under Climate Change

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Abstract

Previous studies showed that climate change undermining the economies and prosperity of the countries within the Greater Horn of Africa (GHA) and their people. The economic performance of the Sudan, particularly agriculture; depends on weather conditions, especially rainfall the major climatic variable. In the last forty years; summer rainfall pattern across the country has been decreasing by 15 to 20 percent, while temperatures have recorded an increasing trend. The purpose of this paper is to examine the main agriculture markets performance under climate change, including their supply, demand, trade and food security variables. The study has developed a stochastic multi-market model for nine major agricultural markets; the model comprises important characteristics of agriculture in Sudan including the dependency of agricultural supply on rainfall and temperature. The markets have been simulated by calibrating supply and demand functions; the climate scenario simulates these markets under climate change of decreasing rainfall and increasing temperatures trends. The model has introduced prices and rainfall as stochastic variables; it has also incorporated national food security indicators like self-sufficiency ratio and the ratio of total export to food imports, which are directly affected by the agriculture performance. The uncertain (Stochastic) variables in the model are presented in their cumulative distribution functions (CDF) by the help of *BestFit*; a software within the @Risk program based on annual observations from 1990-2019. The final results are graphed in the form of cumulative distribution function (CDF). The model scenario simulations revealed that, the impact of the decreasing trend of rainfall and the increasing temperature trend would overall lead to considerable losses to markets supplies and hence a deterioration in the country's external sector and food security situation.

Keywords: Climate change, Stochastic Multi-market model, Sudan, Agricultural Market

1. INTRODUCTION

Sudan population is around 36.2 million inhabitants in 2013. The country has a political system with three levels: federal, state and local. It is divided into 17 states and 133 districts. About 70% of the population is rural. Agriculture is the main economic sector contributing 27% to the GDP and employing about 80% of the workforce (Bank of Sudan, 2015). Primary resources are agricultural, including sorghum, millet, wheat, maize, rice sesame, groundnuts, sunflower, cotton and tomato. The main cropping systems are irrigated farming schemes and rain-fed farming. Major agricultural exports are cotton, sesame, Arabic gum and livestock. Grain sorghum is the principal food crop, and wheat is grown for domestic consumption.

Table (1): GDP economic sectors share (2011-2019)

Years	Agriculture		Industry		Services		Total GDP Growth %
	Share %	Growth %	Share %	Growth %	Share %	Growth %	
2011	31.5	3.3	23.2	-4.3	47.8	5.7	2.7
2012	30.6	5.7	20.4	-12.2	49	3.4	1.4
2013	30.6	3.5	21.1	7.3	48.3	2.1	3.6
2014	28.5	4.1	23.1	10.1	48.4	3.6	2.7
2015	27.9	2.8	23	4.5	49	6.5	4.9
2016	29	3.4	20	5.2	51	7.3	4.1
2017	28	3.7	21	3.6	51	5.6	3.9
2018	28	4.2	22	3.3	50	3.3	2.9
2019	27	3.8	21	4.1	51	2.8	2.3

the extreme south. Rain fall is characterized by significant variations in distribution as well as in timing and location. Previous studies showed that climate change undermining the economies and prosperity of the countries within the Greater Horn of Africa (GHA) and their people. The economic performance of the Sudan, particularly agriculture; depends on weather conditions, especially rainfall the major climatic variable. In the last forty years; summer rainfall pattern across the country has been decreasing by 15 to 20 percent, while temperatures have recorded an increasing trend (IFAD, 2010). Temperature in middle and eastern Sudan has recorded significant increases in winter and autumn minimum temperatures and maximum temperatures during the period 1961-2013, where the average maximum temperature has increased up to 38 C, (Ibrahim, 2015). Future projections till 2050 suggest that the minimum change will be during February by an increase of 1˚C, while the maximum change will occur in November by an increase in of 3 ˚C, while the maximum change will occur in November by an increase in of 3 ˚C. The mean annual change in temperature will increase by 2.7 ˚C (IFAD, 2011).

Climate change is suggested significantly impact agriculture by increasing water demand; limiting crop productivity and production and reducing water availability in sectors where irrigation is most needed. Considerable attention has been given to climate change and its impacts. Agriculture is considered to be one of the sectors most vulnerable to climate

The agricultural sector share in the GDP has a declining trend through the period 2011-2019 (table1), this was attributed to the low investment in agriculture, privatization policies and the growing services sector. The main sectors of agriculture in Sudan are the irrigated sector, rain-fed mechanized, traditional rain fed and livestock sectors. The irrigated agriculture sector area is about 2 million hectares out of about 84 million hectares that are potentially arable. About 93 per cent of the irrigated area was in government projects; the remaining 7 per cent belonged to private owners. The area under rain fed mechanized system covers about 6 million hectares in the state of Gedaref, Blue Nile, Upper Nile, Sinnar and Southern Kordofan. Mechanized farms are usually well over 420 hectares, in this sector Land preparation, seeding, and most threshing on these farms are mechanized, whereas, weeding, harvesting, and some threshing are done manually by seasonal labor. The traditional rain-fed farming system includes, nomadic, transhumant (moving with animals and growing short-maturity subsistence crops), and sedentary farming system which also includes a significant number of livestock. Livestock includes cattle, sheep, goats and camels. The estimates of animal resources are around 104 million heads in 2013 and contribute to 45% of total agriculture sector GDP (BANK of SUDAN, 2014).

Summer is the main rainy season in Sudan; it is extending from May to October, with precipitation ranging between less than 50 mm in the extreme north to more than 600 mm in the products and the perfect competition on the market. The final result depends on the elasticities in the model which are taken as exogenous and constant. The supply and demand equations are represented by isoelastic (Cobb-Douglas) functions in which the price and income elasticities are constant (Kirschke and Jechlitschka, 2002). The supply of each commodity is assumed to be uncertain (stochastic) and represented by the quantity produced which is function of its own price and the prices of the competing commodities in addition to rainfall and temperature as climate elements. In the supply function, quantities, prices rainfall and temperature are considered as stochastic variables and represented in the model by their distributional functional form. On the other hand, the demand (consumption) quantity of a commodity is set to depend on its own price, the prices of close consumption substitutes or complementary commodities and the consumer per capita income. Demand quantities and prices are also calculated in their distributional functional form.

2.1 The Supply Equations

In the model there are nine major commodities. The supply of each is assumed to be uncertain and represented by the quantity produced which is function of its own price and the prices of the competing commodities in addition to rainfall and temperature. Quantities, prices, rainfall and temperature are considered as uncertain variables. The product supply equations represented as follows:

change, and also represents a key sector for international trade. In low-latitude regions, where most developing countries are located, reductions of about 5 to 10 per cent in the yields of major cereal crops are projected (UNEP and WTO, 2009).

Sudan has been assessed to be at risk from the effects of climate change on agriculture (World Bank, 2010), the declining agricultural production in Sudan is worrisome and a real challenge for a government with a population of approximately 30 million to feed. The aim of this paper is to assess the impact of climate change on food security and trade in Sudan. The rest of the paper is organized as follows; the next section presents the methodology of stochastic multi-market model with climate variables. Section three discusses research findings. Section four concludes.

2. METHODOLOGY

A stochastic multi-market model has been developed to simulate Sudanese main agricultural markets and climate change. In the model the interaction between supply and demand functions describes the behavior of producers and consumers in the market. The model starts by formulating supply and demand functions where prices, rainfall and temperature are assumed to play a major role in the model; they work as determination variables of supply and demand equations for the market commodities. Domestic prices are assumed to be linked to world market prices which in turn are determined by the world demand and supply. The model assumes the homogeneity of

$$q_i^s = c_i * (p_i^s)^{\varepsilon_{ii}} * \prod_{j \neq i} (p_j^s)^{\varepsilon_{ij}} * (R^r) * (F^k), \qquad i, j = 1,\ldots,9$$

Where

q_i^s is the amount of the i th commodity supplied?

c_i is the supply calibration coefficient of the i th commodity?

p_i^s is the supply price of the i th commodity?

p_j^s is the supply price of the j th product?

R^r is amount of rainfall.

F Temperature

ε_i is the supply price elasticity of the i th product?

ε_{ij} is the supply cross price elasticity of the j th products that are competing the i th product?

r rainfall elasticity

k temperature elasticity

j is the set of relevant product that compete with the i th product?

2.2 The Demand Equations

On the other hand, the demand (consumption) quantity of a commodity is set to depend on its own price, the prices of close consumption substitutes or complementary commodities and

$$q_i^d = b_i * (p_i^c)^{\eta_{ii}} * \prod_{i \neq j} (p_j^c)^{\eta_{ij}} * I^{\mu_i}, \qquad i,j = 1,\ldots.10 \qquad \cdots \quad (2)$$

q_i^d is the amount of the i th commodity demanded

b_i is the demand calibration coefficient of the i th commodity

the consumer per capita income. Demand and prices are considered as uncertain variables. So, the system of the demand function can be expressed as follows:

Where

p_i^c is the demand price of the i th commodity

I is per capita income

η_i is the demand price elasticity

η_{ij} is the demand price elasticity of the i th commodities that are complementary or substitutes for the i th commodities.

μ_i is the income elasticity of the i th commodity.

$TIm = \sum(q_{i-}^d q_i^s) * p_i^w \quad i = 1,\ldots...9$
(7)

Where, TEx and TIm in the model are the agricultural export and import values.

q_i^s and q_i^d supply and demand of the commodities

p_i^w world market price

2.4.2 Export/import coverage

This index is an alternative to the normalized trade balance. It tells whether or not a country's imports are fully paid for by exports in a given year. In general, economists expect that the trade balance will be zero in the long run, thus imports are financed by exports, but it may vary considerably over shorter periods. The values for this index range from 0 when there are no exports to + ∞ when there are no imports. A ratio of 1 signals full coverage of imports with exports (trade balance).

Export/Import Coverage = $\dfrac{\sum X_j}{\sum M_i}$

(8)

Where,

$\sum X_j$ The bilateral total is export flow, and

$\sum M_i$ The bilateral total import flow.

The term μ_i represents the per capita income of the consumer which is calculated in the model as the outcome of the Gross Domestic Product over the number of total population. This term could also provide the possibility of exploring future developments that may happen in the demand side (Abdel KARIM, 2002).

2.3 Food security indicators

2.3.1 Self-sufficiency ratio (SSR)

Sorghum is the major staple food for the population used as the food security component in the model; whereas, sesame is a cash exportable crop. Self-sufficiency ratio (SSR) is used as food availability indicator.

$SSR = \sum q_i^s / q_i^d \qquad i = 1,2,3$ (4)

2.3.2 Per Capita Consumption (PPC)

$PPC = q_i^d / N \qquad i = 1,2,3$ (5)

Where, N denotes the population number.

2.4 Trade indicators

2.4.1 Total Exports, Total imports

Total agricultural exports, imports and balance of trade are calculated in the model as

$TEx = \sum(q_{i-}^s q_i^d) * p_i^w \quad i = 1,\ldots., 9$
(6)

Wheat is grown in winter under permanent irrigation and affected only by temperature increase, the simulation results figure (1), explain a shift in the CDF curve to the left indicating a fall in wheat supply, that the supply under climate change will reduce to 286,910 tons or less at cumulative probability of 0.6 in compare to 319,332 tons at the same level of probability in the basic scenario. Wheat yields are low due to the unfavorable weather conditions that affect productivity, where relatively high temperatures prevail in Sudan during winter. Wheat yields have varied considerably, sometimes below 1 MT/ha but more often well above 2 MT/ha, especially in recent years. Nevertheless, they are below the average for developing countries as a whole by 25-30%. (Konardeas, 2009).

Sorghum is the main staple food in Sudan particularly in rural areas, it is a summer crop mostly grown under rain fed sector. Therefore, it is affected by both climate variables of rain fall and temperature. The total effect of rain fall and temperature on sorghum supply is shown in figure (2), the CDF function explain that mean supply of 3.4 million tons or less could be attained at cumulative probability of 0.61in the base scenario, while the CDF sorghum mean supply under climate scenario falls to 1.2 million tons or less at the same level of cumulative probability. Sorghum production is quite volatile from year to year as its production follows rain fall fluctuations, the country produces surplus in good rain seasons and some years fall short (El-Dukheri, 2011).The impact on sorghum will affect the country food security as a whole since it was the major component of food security.

Millet is produced and consumed locally, it is also affected by both rain fall and temperature since it is totally produced under the rain fed sector. The CDF simulated mean of millet supply under the base scenario is 573 thousand tons attained at cumulative probability of 0.62 with higher standard deviation. While, under climate scenario the CDF supply mean is around 446 thousand tons at the same cumulative probability level.

2.5 The model scenarios

Two scenarios have been developed in order to simulate the impact of climate change. The first scenario (base scenario) simulates the past period of supply, demand, and environment, and used as base to compare to other simulations. The second scenario (climate change scenario) simulates the nine major commodity markets under climate change of 20% decreasing rainfall and 10% increase in temperature. In each scenario, quantities, prices, rainfall and temperature were presented in their stochastic form. All scenarios were run simultaneously using 1000 random samples from each of the stochastic variable distributions. The BestFit distribution-fitting software program that is bundled with @RISK was used to estimate smooth cumulative distribution functions (CDF) for each scenario based on annual observations from 2000-2015. A time series data for the period 2000-2015 were collected from secondary sources mainly Bank of Sudan annual reports, FAO database, and the World Bank climate knowledge portal. Elasticities of prices and crop yield have been compiled from secondary sources and some regression analysis. Projected increase in per capita income and population has been considered in the model.

In the first step, the distribution of the stochastic variables of supply, demand, prices, rain fall and temperature have been determined with the help of @Risk program. In the second step of the analysis all stochastic variables are applied to the multi-market model and the determined scenarios.

3. RESULTS AND DISCUSSION

3.1 The supply effects

Figures (1), (2) and (3) show the simulation results of climate change scenario on the supply of cereals of wheat, sorghum and millet which constitute the main food security commodities in Sudan. In general the change in climate of decreasing rain fall increasing temperature trends would lead to substantial fall in the supply of cereals.

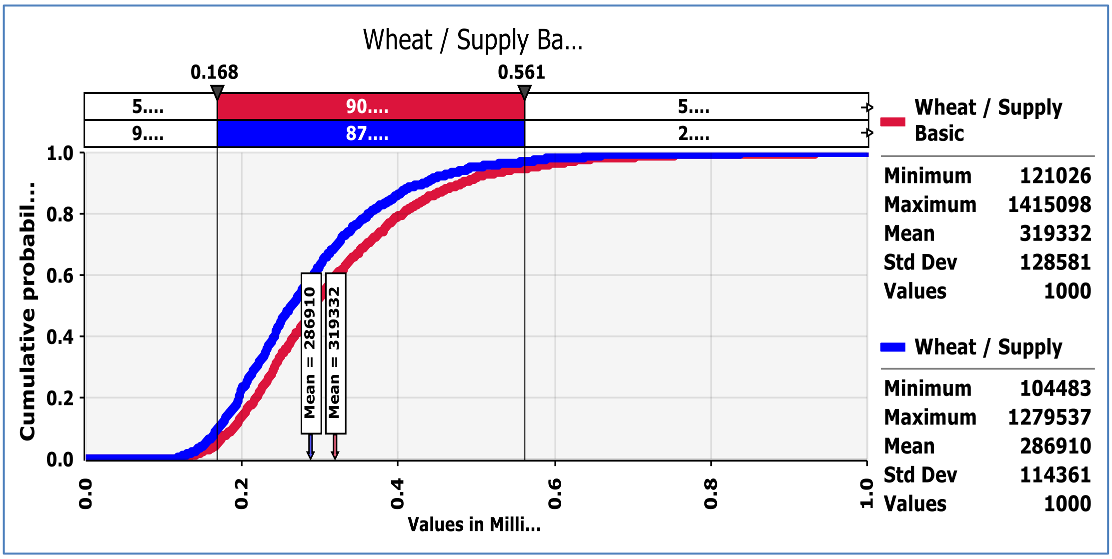

Figure (1): The *CDF* distribution of wheat supply, under the two scenarios

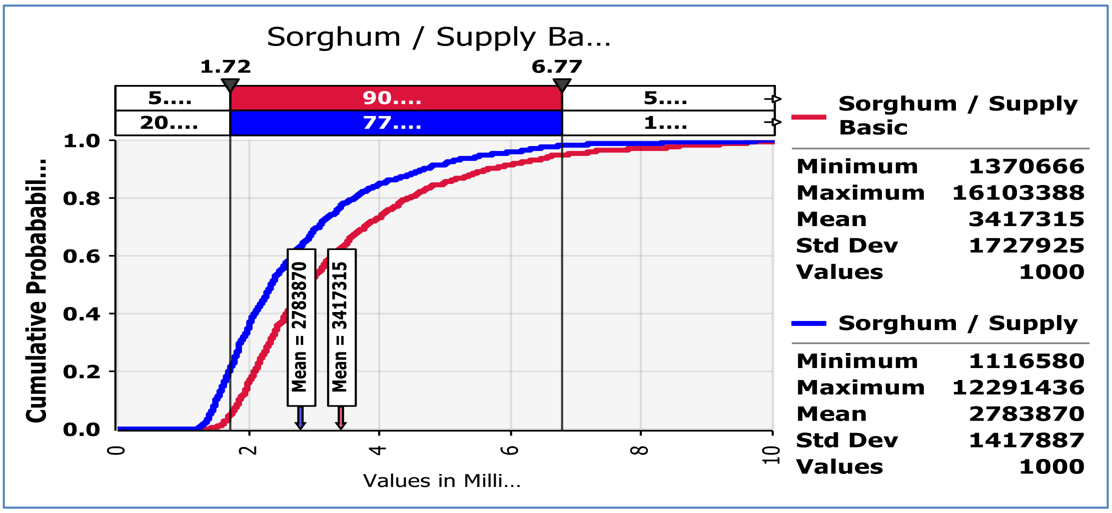

Figure (2): The *CDF* distribution of sorghum supply, under the two scenarios

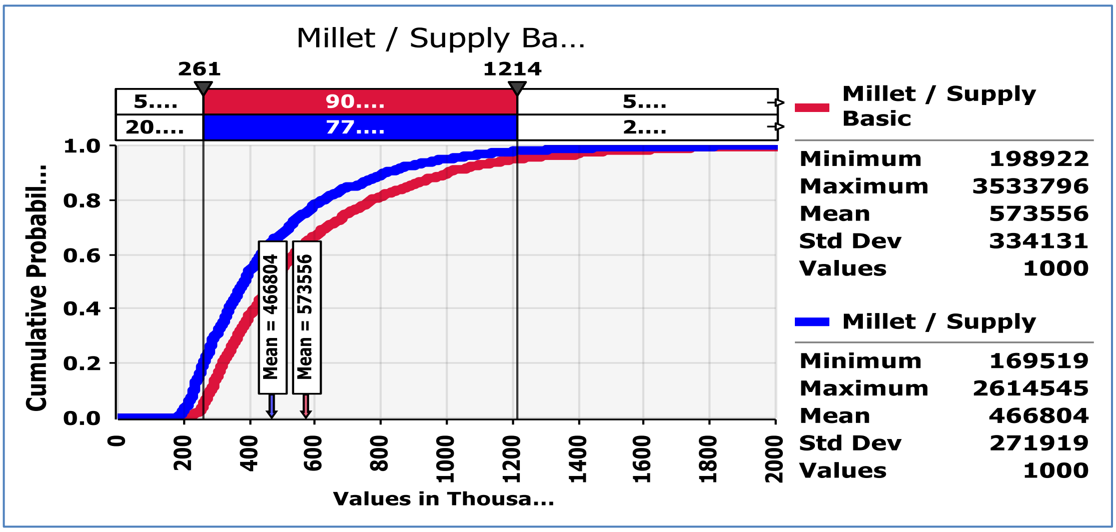

Figure (3): The *CDF* distribution of millet supply, under the two scenarios

an important role in sesame production. Groundnut is another important oil exported crop. It is produced under both the irrigated and rain fed sectors. The CDF distribution graph of groundnuts supply shows that the mean supply could be amounted to 839,199 tons or less at 0.6 cumulative probability in the base scenario, compared to 688,762 tons at the same probability level in the climate change scenario (figure, 5).

Sesame and groundnuts are the most important oil seed crops and considered as cash commodities. Sesame is the major exported crop in Sudan. It is entirely produced under rain fed sector. The CDF simulation results (figure, 4) shows that sesame supplies under the climate scenario amounted to 225,995 tons or less at 0.61cumulative probability; in compare to 313,991 tons or less at the same level of probability in the base scenario. Temperature and the amount and distribution of rain fall play

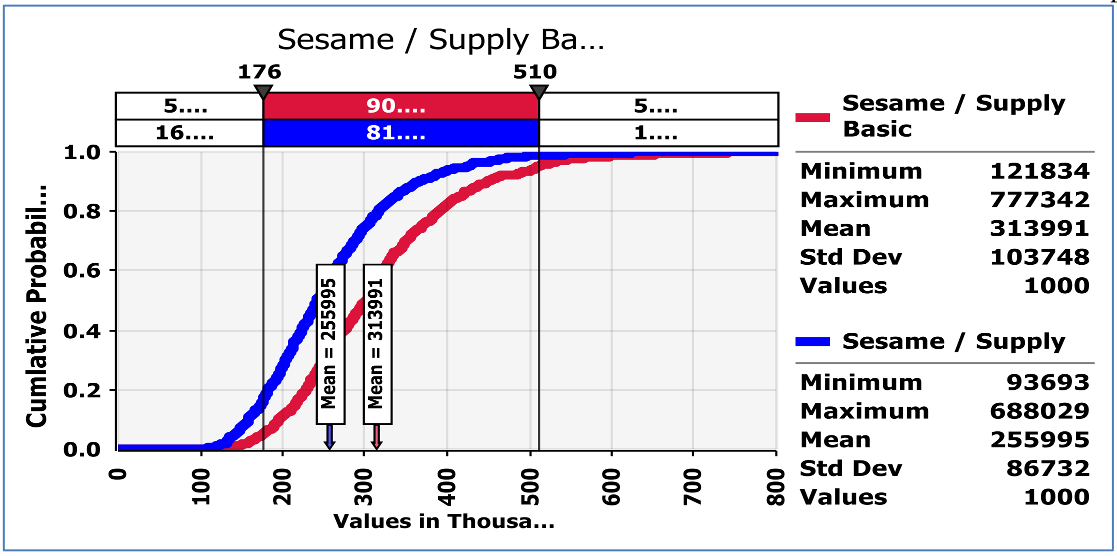

Figure (4): The *CDF* distribution of sesame supply, under the two scenarios

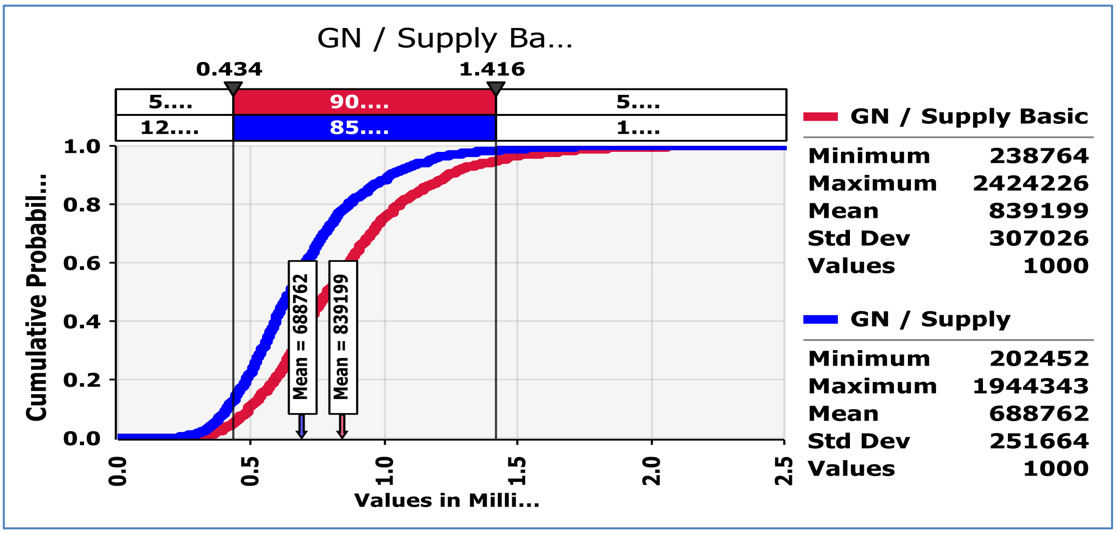

Figure (5): The *CDF* distribution of groundnuts supply, under the two scenarios

scenario that at probability level of 0.6 with mean supply was 130,092 bales or less with regard to 144,968 bales or less at the same probability level. The marginal possible reduction in supply is attributed to the low temperature elasticity.

Cotton is one of the most important commodities in the export list, although its relative share in foreign exchange declined recently. It is affected by temperature, since it is grown under the permanent irrigated sector. In figure (6), the CDF distribution of cotton supply shows a slight decrease in the climate

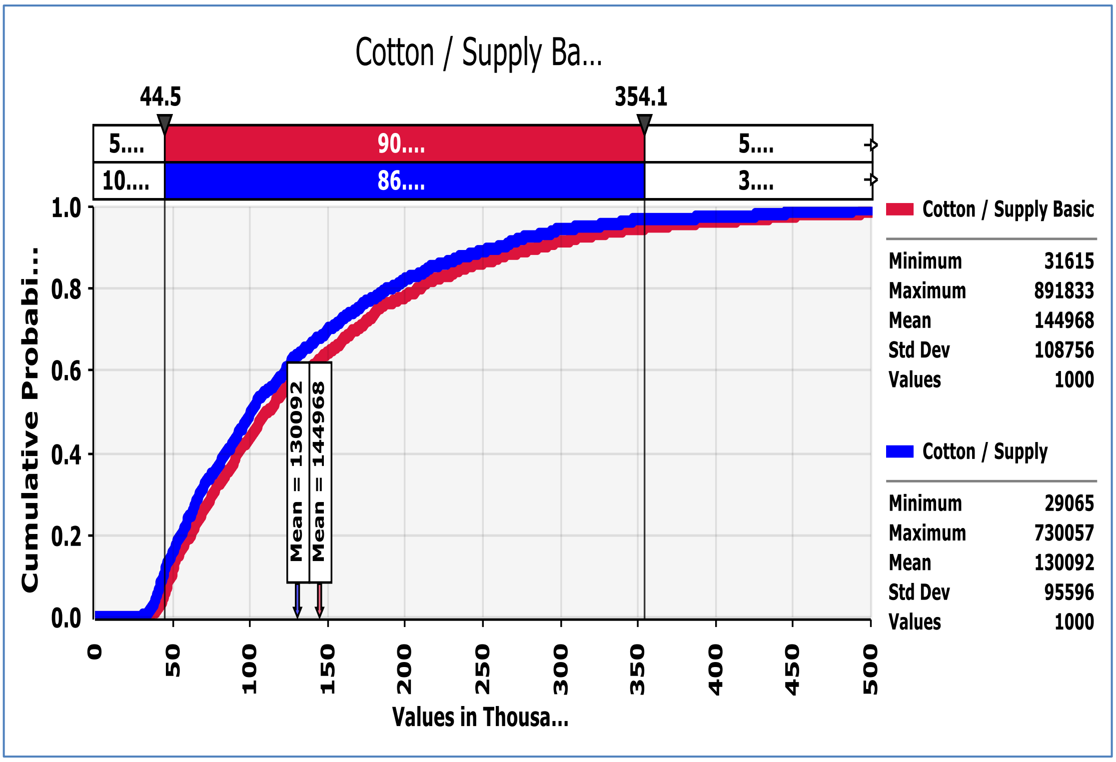

Figure (6): The *CDF* distribution of cotton supply, under the two scenarios

improvement in production efficiency and rational consumption. Sugar supply CDF distribution under climate scenario show a considerable fall to 2624,904 tones or less at 0.6 cumulative probability in compare to 694,349 tons or less at the same probability level in the base scenario (figure, 7).

Sugar production is operated by public companies under permanent irrigated sector; it is also affected by possible temperature rise. Sugar consumption has increased significantly in Sudan. Historically, Sudan has imported the bulk of his requirements; however, the country is self-sufficient in some years as a result of

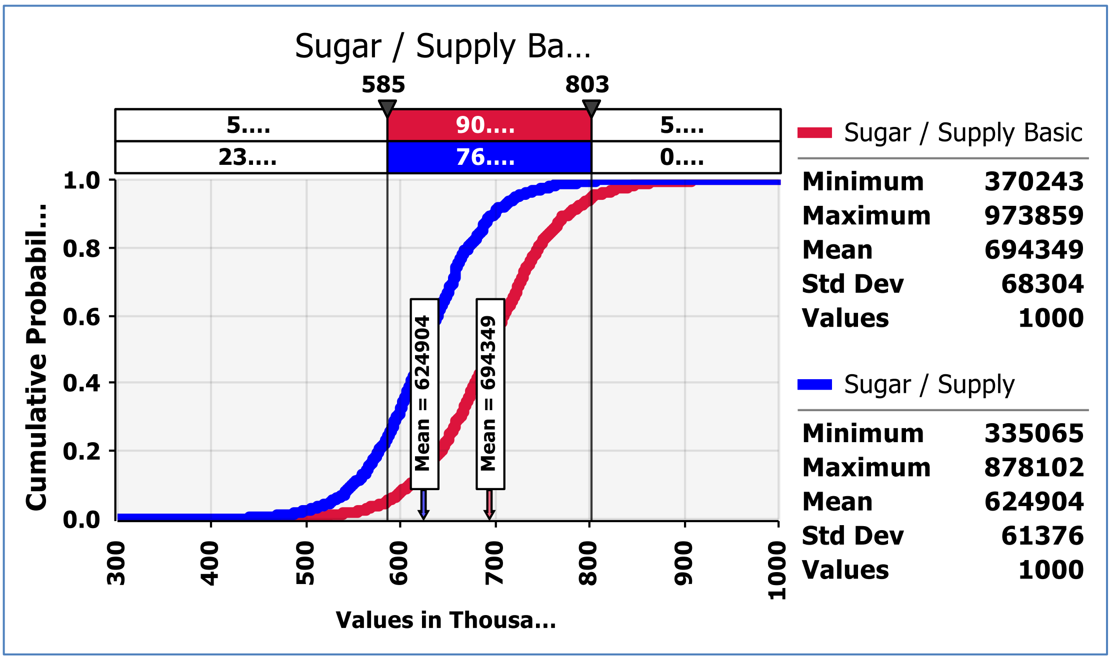

Figure (7): The *CDF* distribution of sugar supply, under the two scenarios

climate scenarios, Arabic gum supplies will be affected directly by rain fall and temperature to fall to 26,264 tons at 0.6 cumulative probability from 29,565 tons at the same level in the base scenario.

Arabic gum is a non-wood forest product, plays an important role in foreign trade of Sudan. The country is a leading producer of Arabic gum; supplying around two third of the total world trading. Figure (8) provides information about the simulation of possible CDF distribution of

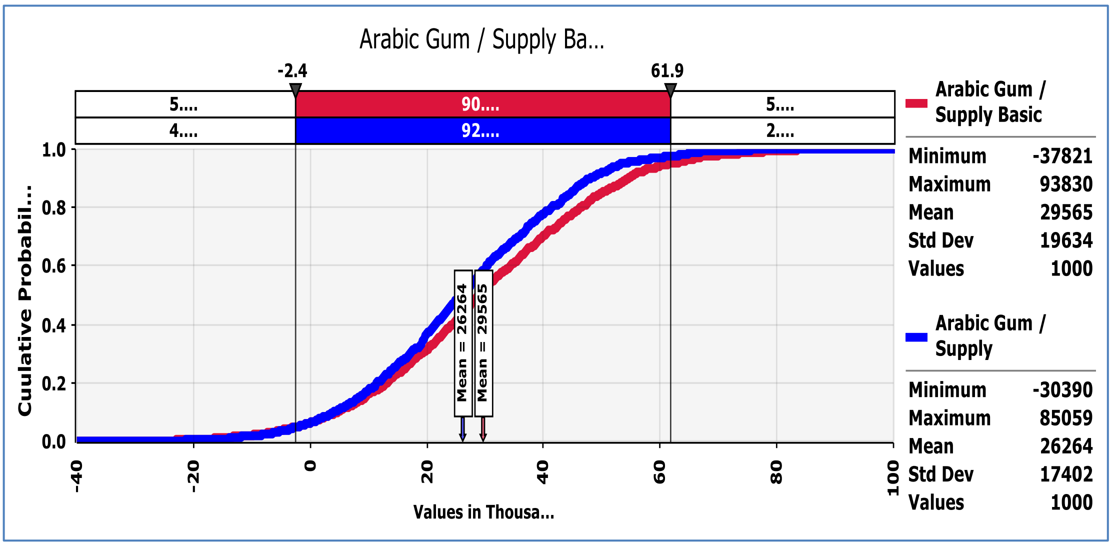

Figure (8): The *CDF* distribution of Arabic gum supply, under the two scenarios

probability where as in the base scenario the possible supply is 45,728,535 at the same probability level. The considerable decline in the supply numbers of livestock is mainly because of that livestock relies on natural pasture in its feeding which in turn depends on rain fall intensity and variability, coupled with temperature effect makes livestock highly responsive to climate change.

Livestock subsector plays basic role in the economy of Sudan. The sector accounts 20-29 percent of the GDP (Bank of Sudan, 2014). It satisfies all domestic consumption of animal products and contributes significantly for foreign exchange earnings through exports of life animal. Figure (9) give an overview of the livestock CDF supply distribution of the model scenarios. Under climate scenario the supply mean would significantly decrease to 39, 580,320 heads or less at 0.7 cumulative

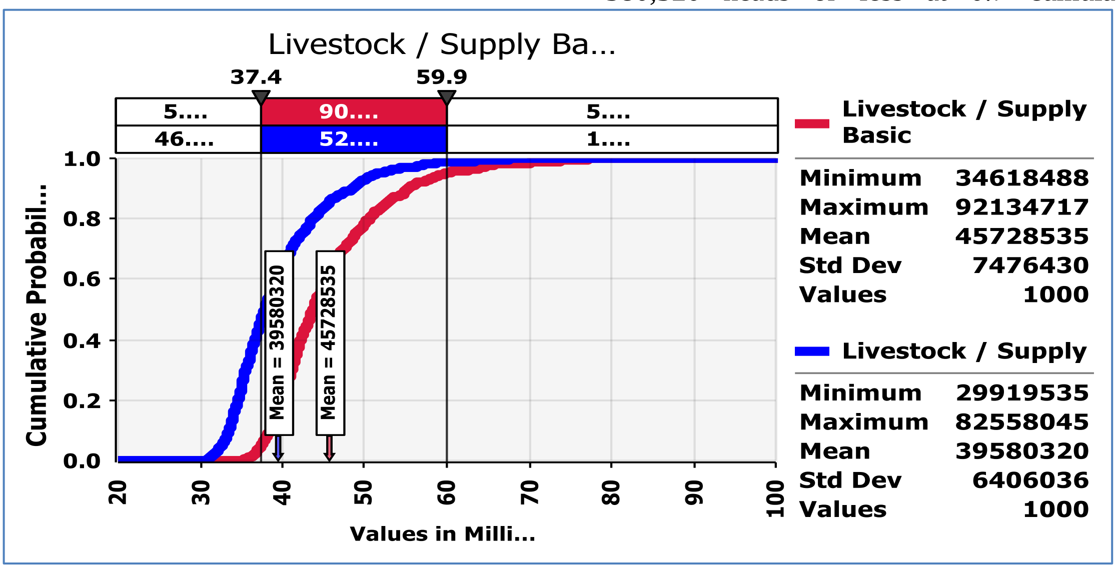

Figure (9): The *CDF* distribution of livestock supply, under the two scenarios

through importing sorghum and millet beside wheat normal imports to secure food availability.

32.2 Per capita consumption (PCC)

Per capita consumption reflects the annual average share of population from domestically produced food security cereals of wheat, sorghum and millet. Figure (11) show the simulated distribution CDF for food per capita consumption indicator for the two scenarios. In the base scenario; the CDF graph shows that the cumulative probability of attaining PPC mean of 199 kg/person/year or less is 0.48, which is highly above east African countries average of 72 kg/person/year (Mkumbwa, 2011). In the climate scenario the PCC mean will decrease to 154 kg/person/year or less at the same level of probability. The reduction PPC in the climate scenario is attributed to the decrease in cereals production resulted from climate change coupled with increase in consumption by the projected increase in population numbers.

In total, self-sufficiency ratio and per capita consumption are indicators for food availability in the country which are expected to face considerable shortages under climate change.

3.2 Food Security effects

3.2.1 Self-sufficiency ratio (SSR)

In the model, the SSR ratio reflects self–sufficiency from food security cereals commodities of wheat, sorghum and millet. Figure (10) shows the simulation results of the CDF graph of the base and climate scenarios. In the base scenario, the ratio could possibly reach 71% or less at 0.48 cumulative probability levels. Sudan is not a self-sufficient of cereals, where, starting from the beginning of the 1980s, the country became a net importer of wheat (Faki, 1996). Sudan's wheat supply and consumption directions have resulted in a continuous and variable deficit between domestic needs and local production. While, the country is normally self- sufficient of sorghum and millet except in low rain seasons and drought times. Under the climate scenario the self-sufficiency could possibly go down to 59% or less at 0.48 probability level as shown by the CDF graph in figure (10). The possible fall in the SSR reflects the expected reduction in wheat, sorghum and millet supplies due to the rain fall decrease and temperature rise in the climate scenario. Under this scenario the country will be obliged to cover its deficit

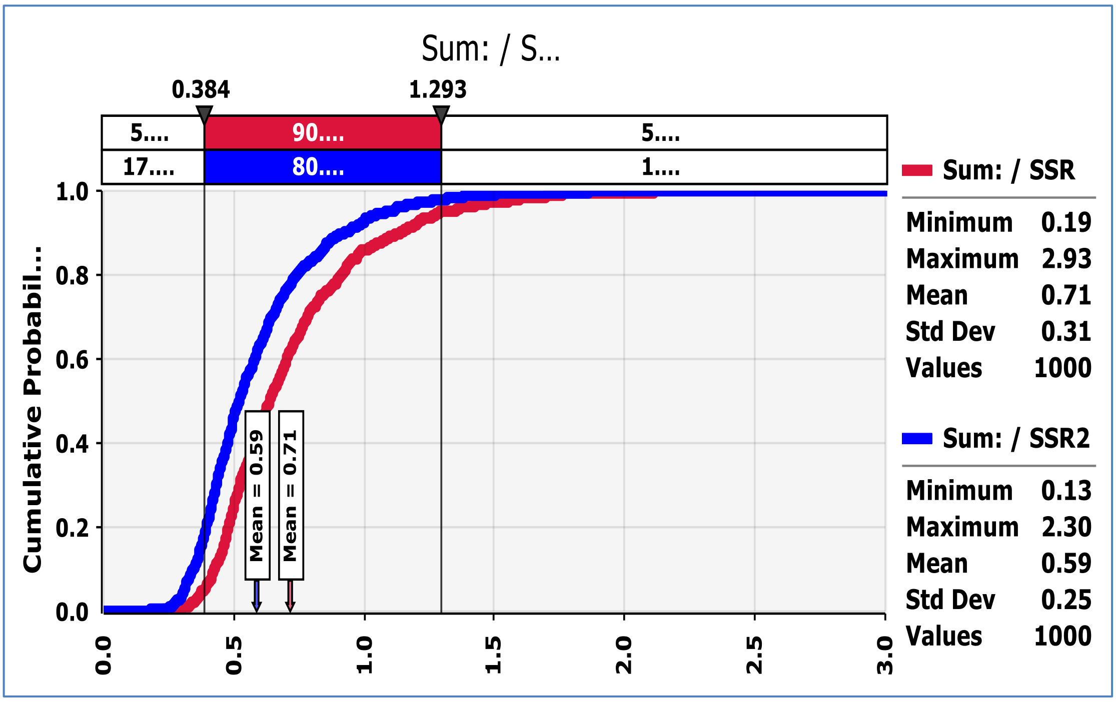

Figure (10): The effect on SSR of wheat, sorghum and millet

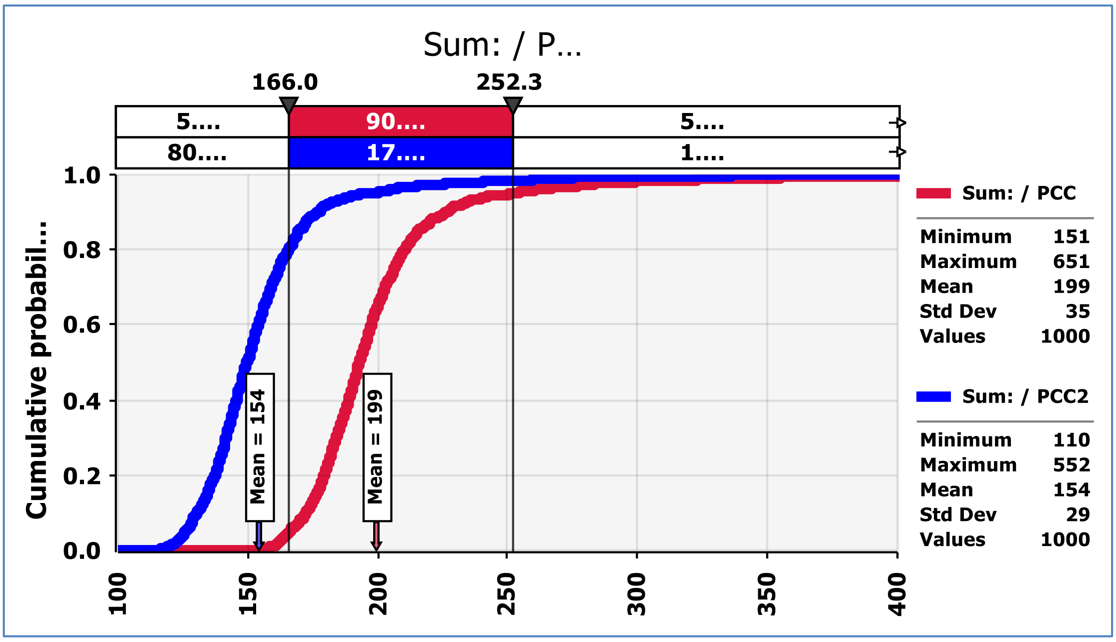

Figure (11): The effect on PPC of wheat, sorghum and millet

increase to US $ 4.3 billion or less at cumulative probability of 0.6, whereas, the base scenario import value is around US $ 1.6 billion at the same level of probability. Therefore, the country is under risk of climate change and possible increases in the world food prices which will aggravate the deficit in trade balance.

3.3.3 Export / import coverage

There is an increasing concern in the country over securing enough resource funds from exports to cover its imports. Figure (14) provides information of the simulation results of the possible outcome of export/import coverage ratio under the two scenarios. The coverage ratio is below one in the base scenario with a mean of 0.96 or less at 0.45 probability level, which indicates the inability of the country to cover all country imports from exports. Under the climate change scenario, the coverage ratio will fall to 0.09 or less at cumulative probability of 0.45; this is because most of the exported commodities have turned into imports. The situation will get worse if there is a possible increase in world food prices and the country will not be able to cover its food imports from exports.

Climate change will negatively affect the agriculture external sector by the direct fall in commodity supplies where the country will turn to be a food net import country. And will affect the sector indirectly that if world food supply

3.3 Trade effect

3.3.1 Total exports

Total exports in the basic scenario are the export value of sorghum, sesame, ground nut, cotton, Arabic Gum and livestock. While, in the climate change scenario the list of exports only includes sesame and cotton, the other commodities would shift to the import list because of the noticeable supply fall in these crops. Figure (12) outlays the simulation results total export value in the two scenarios. The total value of exports will decrease to US $ 116.8 million or less at cumulative probability of 0.6, compared to US $ 828.3 or less million in the basie scenario at the same level of probability. In general, the value of total exports would decrease significantly because of the decrease in exported quantities however; it could be partially compensated from the possible increase in world food prices.

3.3.2 Total Imports

Wheat is major food import substitute. There is an increasing trend of wheat imports and consumption in Sudan. That was attributed to rapid urbanization and the increase in per capita income (Elgali, 2017). In the base scenario the import commodity list consist of wheat and sugar. However, under the climate change scenario the list of imports has extended to include sorghum, millet, ground nut and livestock. Looking at the figure (13), the total value of imports in the climate scenario would offset the export losses because of the shift of most of export commodities to the import list.

falls, prices will increase and consequently increase imports bill. Although there is a possible increase in world prices, but might not

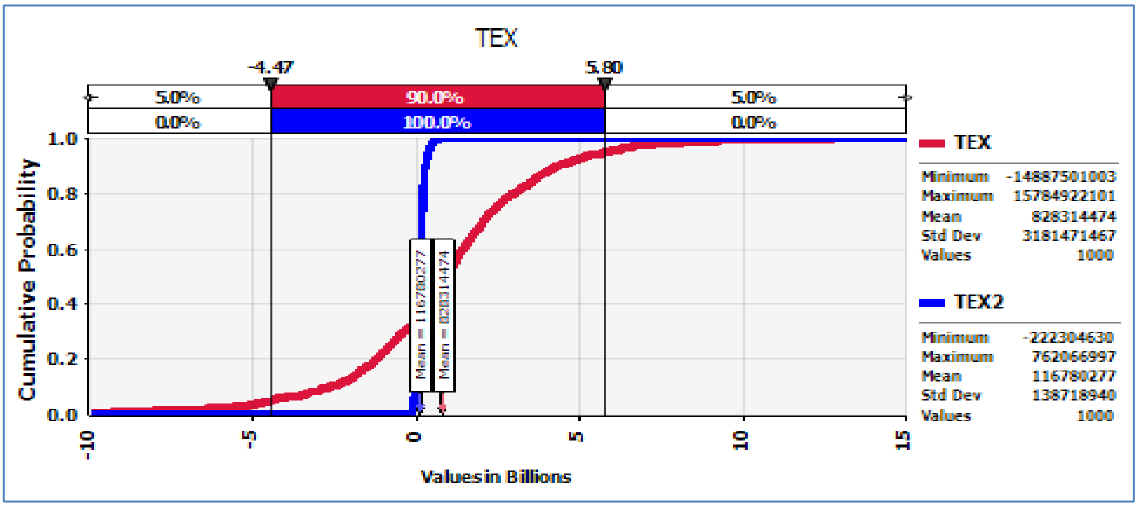

Figure (12): The *CDF* distribution of total exports, under the two scenarios

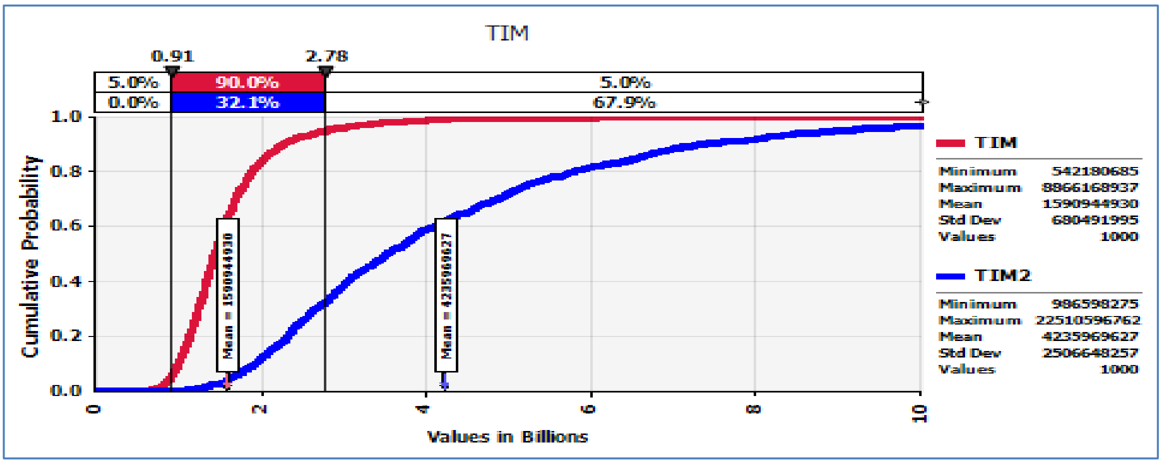

Figure (13): The *CDF* distribution of total imports, under the two scenarios

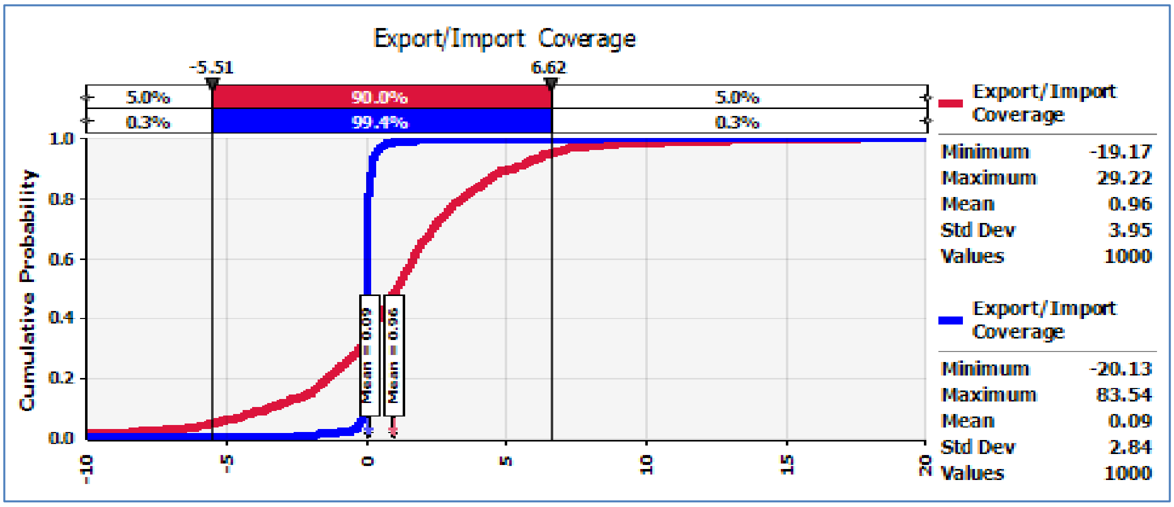

Figure (14): The *CDF* distribution of export/import coverage ratio, under the two scenario

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4. CONCLUSION AND POLICY RECOMMONDATION

The aim of this paper is to assess the impact of climate change on food security and trade in Sudan. The paper has applied a stochastic multi-market model to quantify the possible effects of climate change. The model starts by formulating supply and demand functions where prices, rainfall and temperature are assumed to play a major role in the model; in the supply and demand functions, quantities, prices rainfall and temperature are considered as stochastic variables and represented in the model by their distributional functional form. The model has been extended to include food security and trade indicators.

The overall impact of scenarios simulations of the projected climate variables of rain fall and temperature in the model has reflected in a considerable reduction in the supplies of all commodities covered by the model which have negatively affected food security situation shown by the low ratios of self-sufficiency and per capita consumption. As well as the poor performance of the external sector where total exports have recorded a remarkable decrease in one hand, on the other hand, imports have increased dramatically. Finally, the country will not be able to cover its imports of food through its agricultural exports. Interventions to mitigate and adapt to potential adverse impacts of climate change by the horizontal expansion in the permanent irrigated sector is needed, where the adverse impact of climate change is lower than the rain fed sector. Such interventions would have important implications for future food security, trade and overall growth of the economy.

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